DOCUMENT RESUME

ED 053 930 SE 012 016

AUTHOR	Simmons, Gene
TITLE	On the Moon with Apollo 15, A Guidebook to Hadley Rille and the Apennine Mountains.
INSTITUTION	National Aeronautics and Space Administration, Washington, D.C.
PUB DATE	Jun 71
NOTE	52p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (3300-0384 $0.50)
EDRS PRICE	EDRS Price MF-$0.65 HC-$3.29
DESCRIPTORS	*Aerospace Technology, Geology, Reading Materials, Resource Materials
IDENTIFIERS	*Lunar Studies, Moon

ABSTRACT

The booklet, published before the Apollo 15 mission, gives a timeline for the mission; describes and illustrates the physiography of the landing site; and describes and illustrates each lunar surface scientific experiment. Separate timelines are included for all traverses (the traverses are the Moon walks and, for Apollo 15, the Moon rides in the Rover) with descriptions of activities at each traverse stop. Each member of the crew and the backup crew is identified. Also included is a bibliography of lunar literature and glossary of terms used in lunar studies. Photographs and diagrams are utilized throughout. Content is descriptive and informative but with a minimum of technical detail. (Author/PR)

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ON THE MOON WITH APOLLO 15

A Guidebook to Hadley Rille and the Apennine Mountains

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

June 1971

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ON THE MOON WITH APOLLO 15

A Guidebook to Hadley Rille and the Apennine Mountains

by

Gene Simmons

Chief Scientist

Manned Spacecraft Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

June 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents
Stock Number 3300-0384

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PREFACE

Never before in man's history has it been possible for more than a few people to witness major scientific discoveries. Yet with each Apollo mission to the Moon's surface, millions of people throughout the world can watch through television the activities of the astronauts. The understanding by the viewer of those activities and his sense of sharing in the scientific excitement of the mission are greatly increased when there is a general understanding of the scientific and engineering aspects. Yet for most of us, the usual discussions are clouded with jargon.

My purpose in writing this guidebook is to give in simple terms information about the Apollo 15 mission to the Moon's surface so you can share with me the excitement of the scientific exploration of the Hadley-Apennine region of the Moon.

Many people helped me prepare this guidebook. Richard Baldwin and Gordon Tevedahl collected background material. George Gaffney coordinated all art work. Jerry Elmore, Norman Tiller, Ray Bruneau and Boyd Mounce drew most of the original sketches. Andrew Patnesky provided several new photographs. The manuscript was improved greatly as a result of comments by Jack Schmitt, George Abbey, Verl Wilmarth, James Head, Donald Beattie, Rosemary Wang, Herbert Wang, Ruth Zaplin, Mary Jane Tipton, and my seventeen-year-old daughter Debra. My secretary Jean Ellis helped with many revisions. To all of these people, I express my thanks.

GENE SIMMONS
May 1971
Nassau Bay

HOW TO USE THIS GUIDEBOOK

Excellent commentaries have been available over television for each previous Apollo mission. However, because of the increased complexity of the surface operations on Apollo 15 and because of the greater amount of time devoted to science-activities, I believe that a written guide would be welcomed by the interested viewer of Apollo 15. The material in this guidebook is intended to be used in conjunction with the other material shown over commercial TV.

The science-activities of the astronauts on the surface are divided between "experiments" and "traverses". For the experiments, the astronauts set up equipment on the Moon that collects data and (generally) transmits the data back to Earth. These experiments are described briefly in the section "Lunar Surface Scientific Experiments and Hardware". The reader need not read about all the details of each experiment on first reading. Quite frankly, even I find that section somewhat tedious to read, probably because it is rather complete, but I have chosen to keep it in the present form so that you may refer to the individual experiments as you wish. I do recommend scanning this section before the first EVA in order to understand something about each of the experiments.

Most of the astronaut's time on the lunar surface will be spent on the traverses. The section "Traverse Descriptions" is a guide to those activities. It tells in general terms the things the astronauts will do on each traverse and indicates what they will do next. It should be used in the same way that a flexible itinerary for a vacation trip through New England would be used. Refer to it during the traverse. But do not try to read it in great detail before the traverse.

The section "Lunar Geology Experiment" should be read before the traverses begin. There you will find descriptions of the tools that are used, the various kinds of photographs taken, and so on.

Finally, you should know that a glossary and list of acronyms are included in the rear of the guidebook. I expect the definitions and short discussions to be found there will help in understanding some of the terms and concepts now in common use in the scientific exploration of the Moon.

Introduction

The Apollo 15 mission to the Moon's surface is expected to be launched from Cape Kennedy on 26 July 1971 and to land a few days later near a very large and majestic mountain range, the Apennine Mountains. A sketch of the front side of the Moon is shown in figure 1 and the location of the landing site is shown in relation to other sites. This landing site is extremely attractive from the viewpoint of lunar science. It will give the astronauts their first chance to collect rocks from lunar mountains and to study at firsthand a feature, termed rille, which resembles in many ways the channels cut on Earth by meandering streams. The origin of rilles is probably not the same as that of the familiar terrestrial stream-cut channels because no water is present now on the Moon's surface and probably never existed there. The origin of rilles is a puzzle.

Near the landing site are Hadley Mountain, which rises about 14,000 feet above the surrounding lowlands and Mount Hadley Delta, which rises about 11,000 feet. The actual surface on which the Lunar Module or LM* will land is everywhere pock-marked by craters of various sizes. The smallest craters known are less than $\frac{1}{1000}$ inch across; the largest exceed 50 miles. The craters were produced during the past few million years when objects from space struck the Moon. The craters are still being produced but there is no danger to the astronaut because collisions with the Moon are very infrequent. For example, an object larger than birdseed would strike the landing site only once every few years. But because erosion is so slow on the Moon, the craters produced millions of years ago are still preserved and appear as seen in photographs throughout this guidebook. The mechanisms of erosion, the process by which rocks and soil are removed from a particular spot, are very different on the Earth and the Moon. Most terrestrial erosion is accomplished by running water and is relatively rapid. Most lunar erosion is the result of impacting objects and the resulting craters destroy previously existing ones.

Since the first manned lunar landing, Apollo 11, in July 1969, significant improvements in both equipment and procedures have increased dramatically the capabilities of Apollo 15 over those of previous missions. Total duration of the mission has increased from 9 days to a planned time of about 12½ days and a maximum of 16 days. Actual time for the LM to remain on the lunar surface has doubled, from 33.5 hours previously to a planned 67.3 hours. The amount of time spent by the astronauts on the lunar surface outside the LM, which has become known as Extravehicular Activity or EVA, has more than doubled from a maximum of 9.3 hours previously to a planned 20 hours. The EVA time will be spent in three periods of 7, 7, and 6 hours' duration. The weight of the scientific equipment that will be used in lunar orbit has increased from 250 pounds to 1,050 pounds. The weight of the scientific equipment to be landed on the lunar surface has increased from 510 pounds to about 1200 pounds. And finally, the astronauts will have with them for the first time a small, four-wheeled vehicle for travel over the Moon's surface. It is termed Rover and can carry two astronauts, equipment, and rocks. Unlike the Russian vehicle Lunokhod that was recently landed and is still operating, it cannot be operated remotely from Earth.

A summary of major events for the entire Apollo 15 mission is shown in Table 1. Scientific activities while the spacecraft is in orbit around the Earth, consist mainly in photographing the Earth with film that is sensitive to ultraviolet (uv) radiation for the purpose of examining various terrestrial, cloud, and water features. By using uv, we hope to "see" these features more clearly than we could see

*Abbreviations and acronyms are very useful in situations where time is limited, such as a mission to the Moon's surface. Common ones are noted in this book where first used. An extensive list is given at the end of the text.

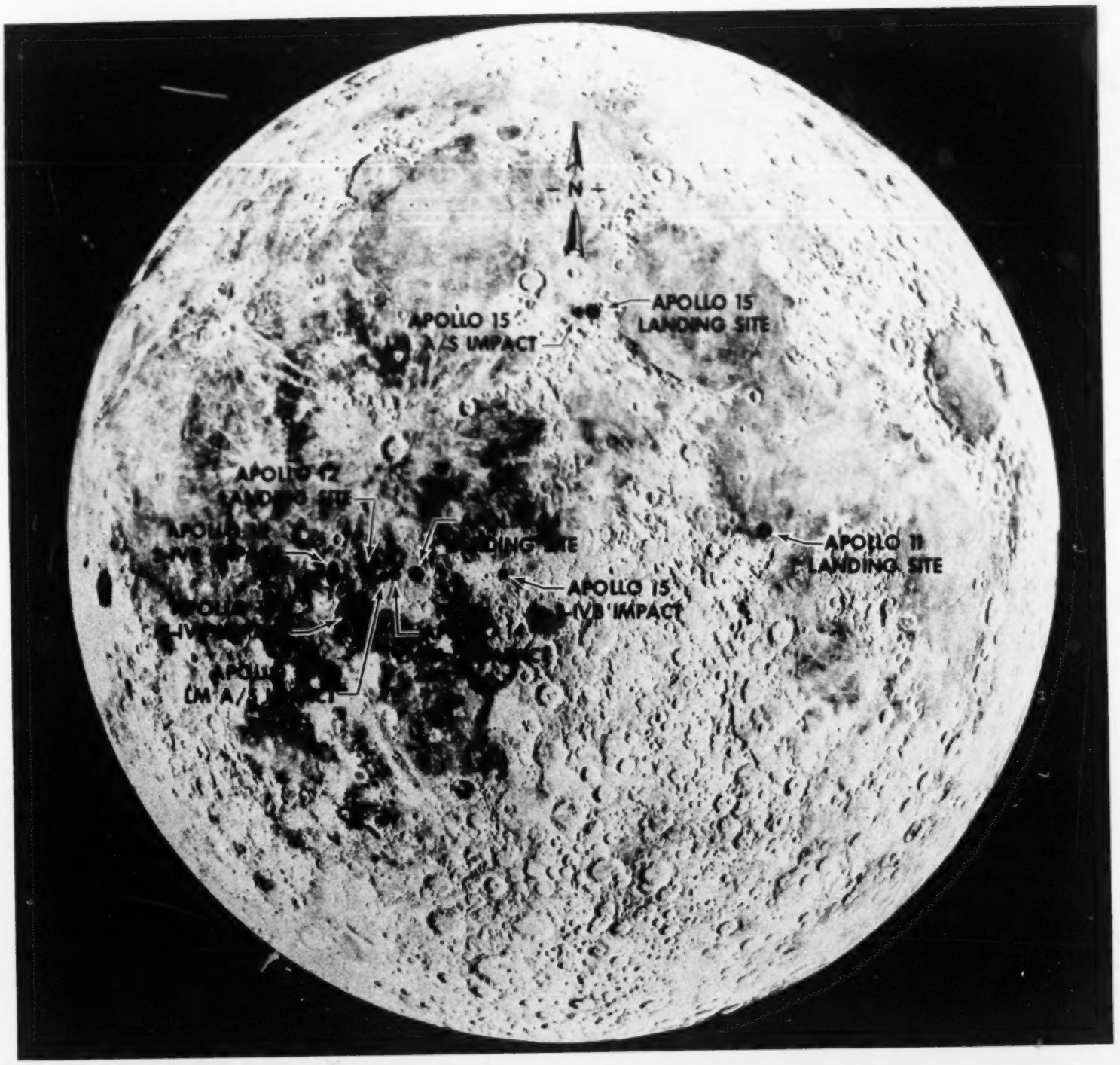

FIGURE 1.—Front side of the Moon. This side always faces the Earth. Shown here are locations of the previous Apollo landings and of the impacts on the Moon of spent S–IVB stages and LM ascent stages. The impacts create sound waves in the Moon that are used to study the interior of the Moon.

them with visible light. From space, the atmosphere gets in the way of seeing. The situation is somewhat akin to that of using sunglasses to reduce glare, so the wearer can see better. The uv photography will be continued during the journey to the Moon and pictures will be obtained at various distances from the Earth. During this journey and before the landing on the Moon, one of the spent stages of the rockets that were used to lift the spacecraft from the Earth, and designated S–IVB, will be crashed into the Moon. The sound waves generated by the S–IVB impact travel *through* the Moon and will be detected by sensitive receivers (seismometers) now operating at the Apollo 12 and 14 sites. (This experiment is discussed more fully later in this guidebook.)

Shortly after placing their spacecraft in orbit about the Moon, the astronauts separate it into two parts. One part, the combined Command and Service Modules (CSM), remains in lunar orbit while the other part, the Lunar Module (LM), descends to the surface.

One astronaut remains in the CSM and performs many scientific experiments. These orbital experiments will obtain data over a large part of both front and back sides of the Moon because the path of the point directly beneath the spacecraft, termed ground track, is different for each revolution of the spacecraft. See figure 2. Notice that the orbit of the CSM is not parallel to the equator. If the Moon did not rotate about its axis, the ground track would change very little on each successive revolution of the CSM. However, the Moon does rotate slowly about its axis. It completes one full revolution every 28 earth-days and therefore the ground track is different for each CSM revolution.

Several of these orbital experiments will measure the approximate chemical composition of the Moon's surface materials. Others are intended to measure the variations of gravity and of the magnetic field around the Moon. A laser altimeter will be used to obtain precise elevations of features that lie on the Moon's surface beneath the orbiting CSM. An extensive set of photographs will be obtained. The pilot will observe and photograph many features on the Moon never before available to astronauts.

The other two astronauts descend to the surface of the Moon in the LM. The rest of this guidebook is a discussion of their equipment and of their activities.

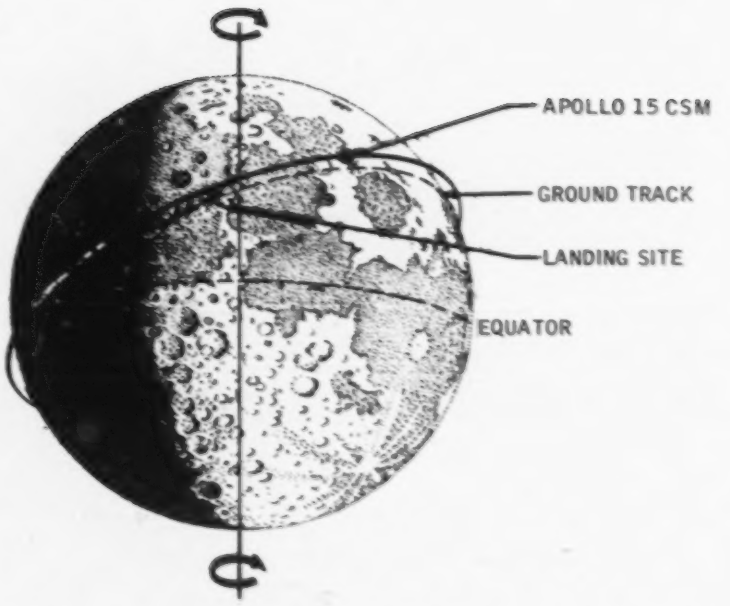

FIGURE 2.—Trajectory and ground track of Apollo 15. Because the Moon rotates, the ground track is different for each revolution of the CSM.

The LM, illustrated in figure 3, lands two astronauts on the Moon's surface. It has two parts, a descent stage and an ascent stage. The descent stage contains a rocket engine, fuel necessary to land both stages, a four-wheeled battery-powered vehicle to be used on the Moon, water and oxygen, and scientific equipment to be left on the Moon when the astronauts return to Earth. The other part, the ascent stage, contains the following items: (1) equipment for communications with the Earth and with the CSM, (2) navigational equipment, (3) a computer, (4) food, oxygen, and other life-support supplies, and (5) another rocket engine and fuel needed to leave the Moon and rendezvous with the CSM. All three astronauts return to Earth in the Command Module.

Soon after the LM lands on the Moon, about 1½ hours, the astronauts will spend a half hour describing and photographing the surrounding area. The commander will open the upper hatch and stand with his head and shoulders outside the LM. During this Standup Extravehicular Activity (SEVA), the LM cabin will be open to the lunar atmosphere and will therefore be under vacuum conditions. Both astronauts must wear their space suits. Because the commander's head will be above the LM, he will have excellent visibility of the landing site. If the LM lands within 100 yards, the length of a football field, of the planned spot, then the commander will see the panoramic view

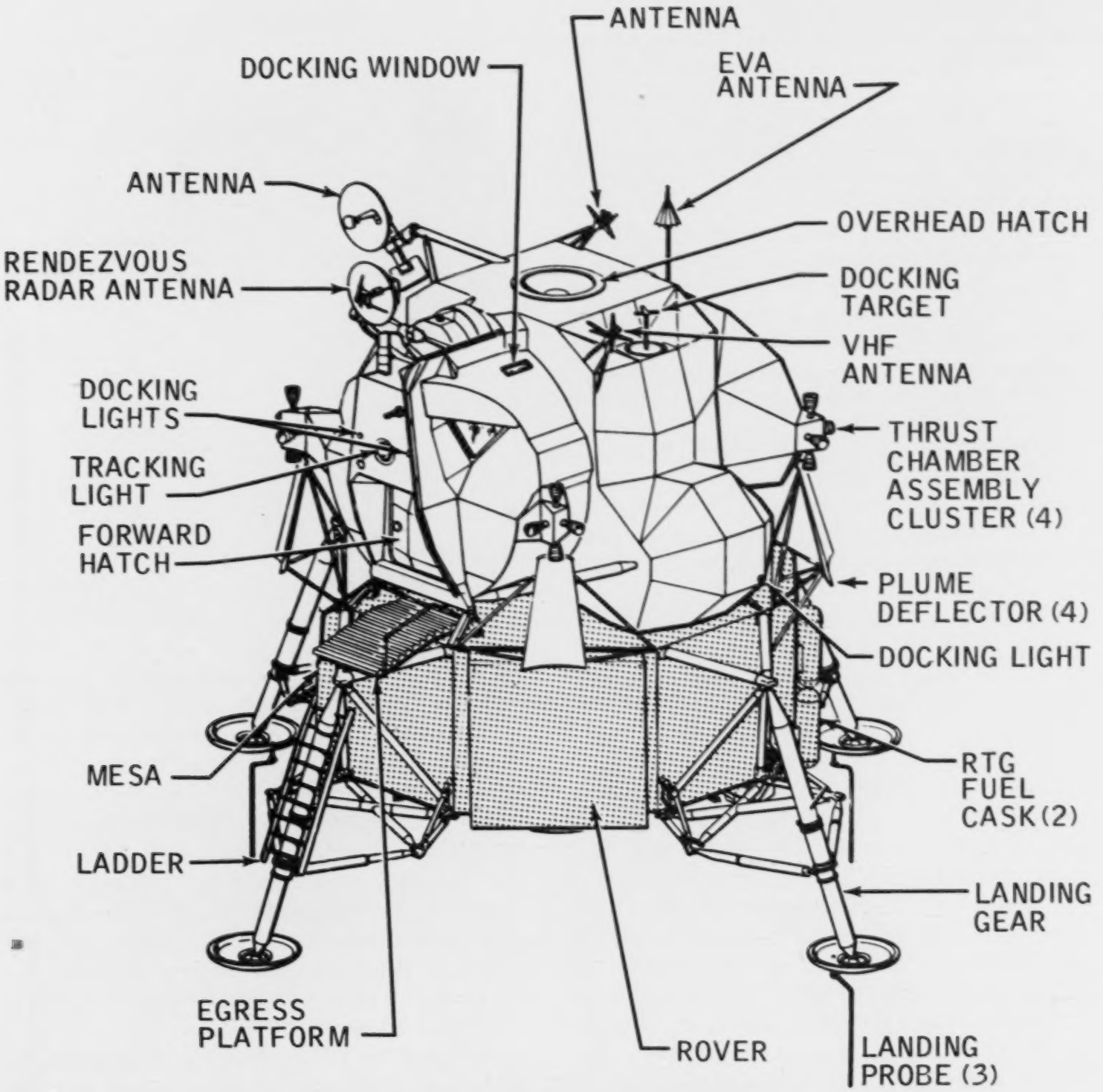

FIGURE 3.—The Lunar Module (LM). The shaded portion, the descent stage, remains on the Moon when the astronauts leave in the ascent stage to rendezvous with the CM and return to Earth.

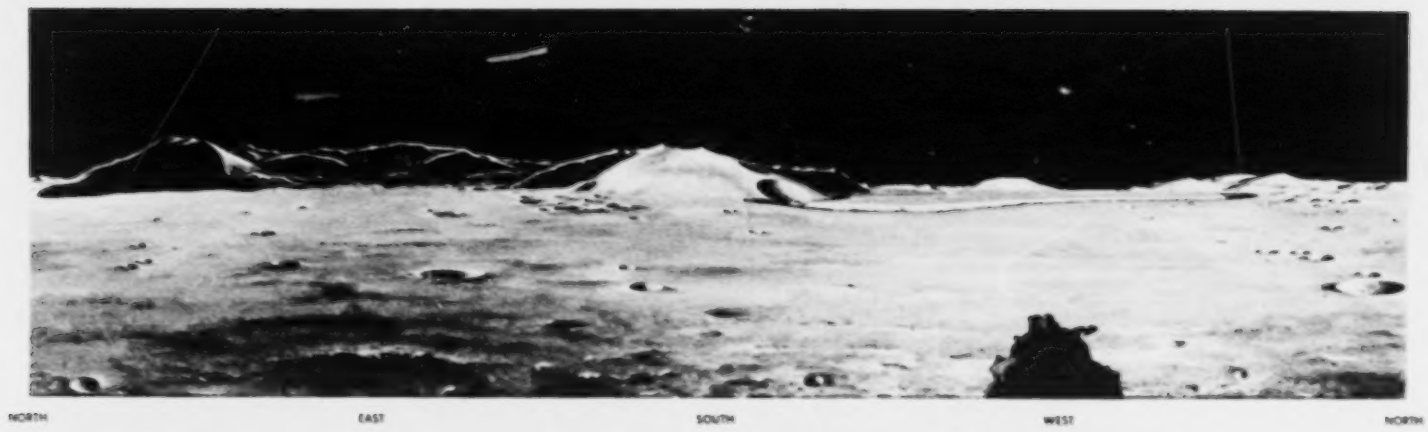

FIGURE 4.—SEVA Panorama. Artist Jerry Elmore has depicted here the panorama that the Commander will see from his vantage point above the LM during the SEVA. Mount Hadley Delta, due south, stands about 11,000 feet above the landing site. Hadley Mountain, the large dark mountain situated northeast of the site, is about 3,000 feet higher than Mount Hadley Delta.

sketched in figure 4. He will shoot photographs, which will include panoramas, with both 500 mm and 60 mm lens. His verbal descriptions during the SEVA will help Mission Control to accurately pinpoint the actual landing site. Of equal importance is the fact that the descriptions will assist in the continuing evaluation of the surface science plans. It is likely that the astronauts will draw attention during the SEVA to some surface features, previously overlooked, that we will wish to examine sometime during the three EVA's.

When the astronauts leave the LM, a process appropriately termed egress and shown in figure 5, they must wear a suit that protects them from the Moon's high vacuum. This suit is illustrated in figure 6. Although it was designed to allow freedom of movement, it still restricts considerably the motion of the astronauts. An example may be useful. Think how difficult it is to run, chop wood, or work outdoors on an extremely cold day in winter when you wear many layers of clothes. The astronauts' suits are even more restrictive. The Portable Life Support System (PLSS) contains the oxygen needed by the astronaut and radios for communication. It also maintains the temperature inside the suit at a comfortable level for the astronaut.

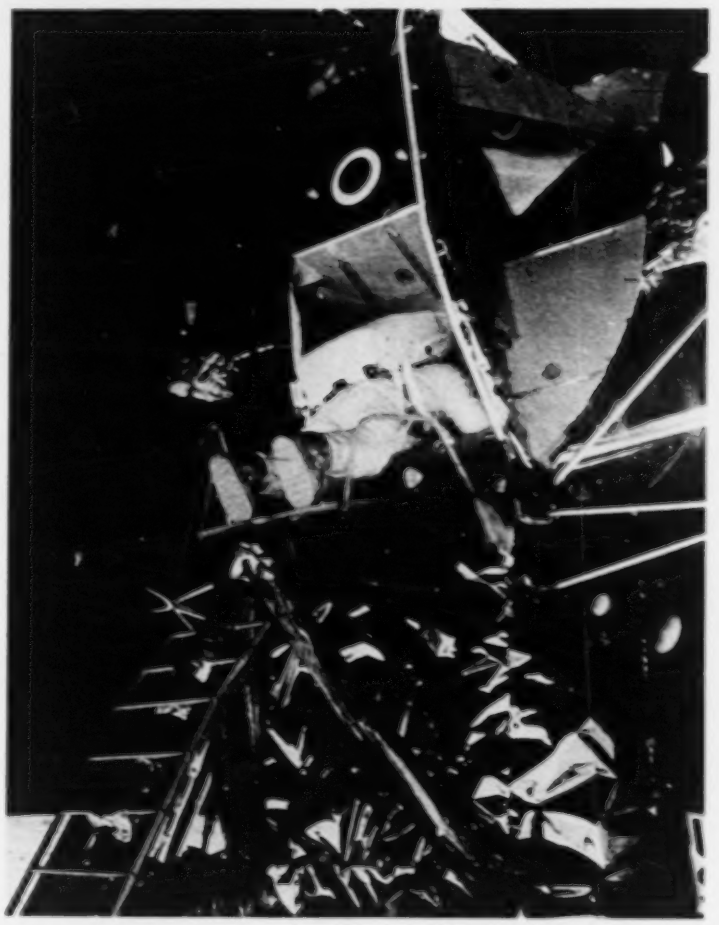

FIGURE 5.—Egress. Apollo 11 astronaut Aldrin is shown egressing from the LM. Note the ladder that leads down one leg from the platform.

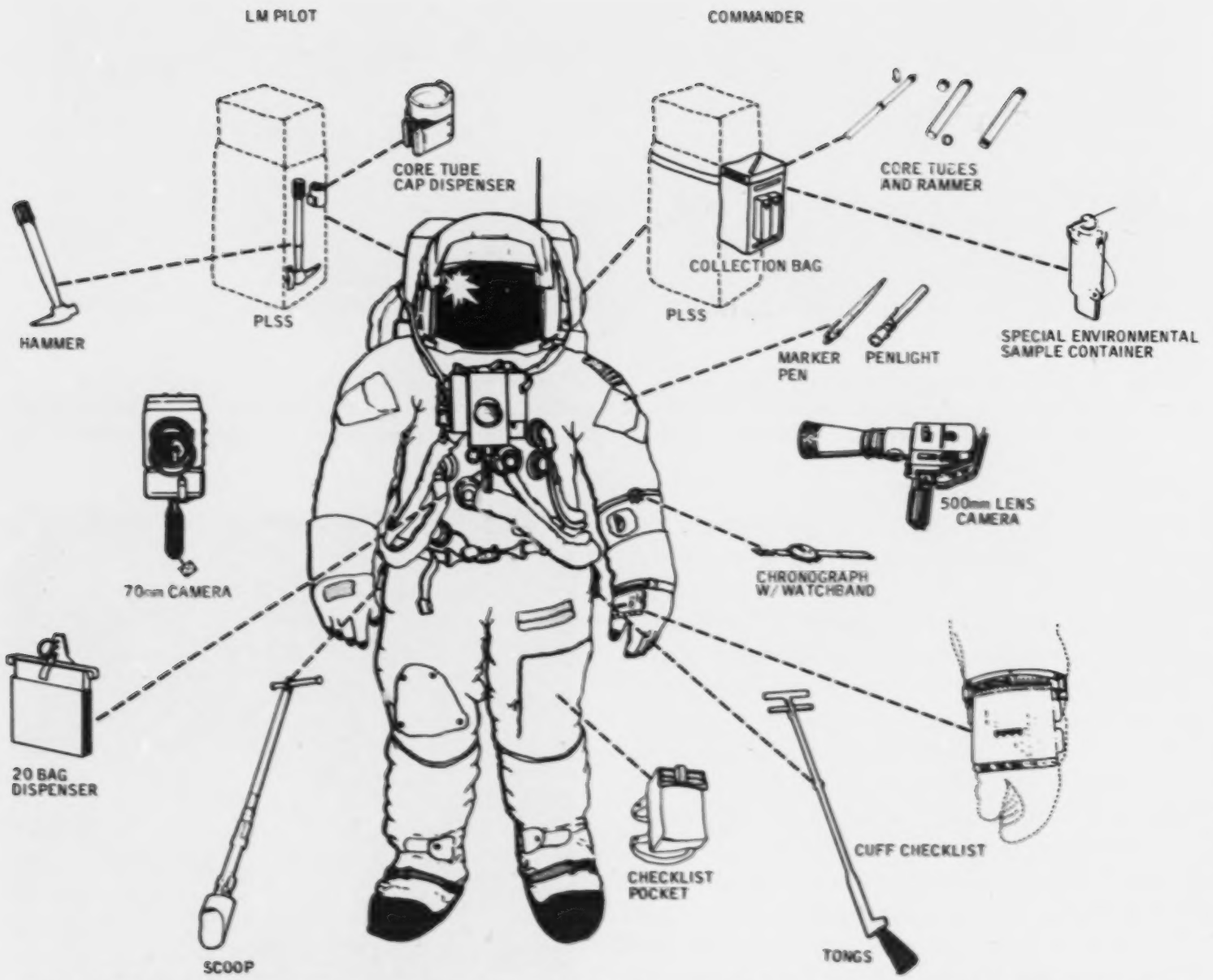

FIGURE 6.—Astronaut suit. The suit prevents exposure of the astronaut to the Moon's vacuum. It incorporates many improvements over the suits used on previous Apollo flights. Sketched also are several items of equipment.

Landing Site Description

The Apollo 15 landing area, termed Hadley-Apennine, is situated in the north central part of the Moon (latitude 26° 04′ 54″ N. longitude 03° 39′ 30″ E) at the western foot of the majestic Apennine Mountains, and by the side of Hadley Rille. See figure 1. The Apennines rise 12,000 to 15,000 feet above the lunar surface and ring the southeastern edge of Mare Imbrium (Sea of Rains). For comparison with Earth features, the steep western edge of the Apennine Mountains is higher than either the eastern face of the Sierra Nevadas in the western U.S. or the edge of the Himalayan Mountains that rises several thousand feet above the plains of India. The actual landing point was selected so the astronauts could study the sinuous Hadley Rille, the Apennine Mountains and several other geological features. A beautiful perspective view of the local landing site, as seen from an angle of about 30 degrees, is shown in figure 7. In drawing this figure, we have combined the precision that is available from modern-day digital computers and the insights that can come only from an artist. Thus the features are very accurately drawn but they are displayed in a way that the human eye will see them.

In the rest of this section, I will discuss the several geologic features present at the landing site: The Apennine Mountains, Hadley Rille, the cluster of craters at the foot of Hadley Mountain, and the North Complex. All of them are clearly visible in figure 7.

THE APENNINE MOUNTAINS

These mountains form part of the southeastern boundary of Mare Imbrium and are believed to have been formed at the same time as the Imbrium basin.*

*To the scientist, the distinction between a mare, which is the surface material, and the associated basin, which includes the shape and distribution of materials at depth beneath the mare, is very important.

The general relations of the Apennine Mountains, Hadley Rille, and a branch of the Apennine Mountain chain, termed Apennine Ridge, are seen in figure 8. Most lunar scientists agree that the Imbrium basin was formed by impact of a large object but there is no general agreement on the details of the processes involved in the origin of the rille or the mountains. One possible process of basin formation is shown schematically in figure 9. The impact of the object causes material to be thrown out in much the same way that material is splashed when a large rock is dropped in soft mud. From a study of the samples of material that is ejected from the crater, we can measure the age of the material and obtain the date at which the impact occurred. We can also determine the nature of the material at depth in the Moon. I think it is very likely that most of the material available for sampling at the Apollo 15 landing site consists of rocks and soil ejected from Imbrium basin. Some material older than the Imbrium impact may be found at the base of Mount Hadley Delta. Thus one of the main geological goals of this mission is to sample those rocks.

Our understanding of the details of crater formation has been improved by the study of impact craters on Earth. One such crater that is generally well-known is Meteor Crater, near Flagstaff, Arizona. Other impact craters, less well-known but intensely studied by geologists, exist in Tennessee, Canada, Australia, Germany, and elsewhere. An oblique photograph of Meteor Crater is shown in figure 10.

HADLEY RILLE

Hadley Rille is a V-shaped sinuous rille that roughly parallels the Apennine Mountains along the eastern boundary of Mare Imbrium (figures 7 and 8). It originates in an elongated depression in an area of low domes that are probably volcanic in nature. It has an average width of about

FIGURE 7.—Landing site for Apollo 15 as seen from the north. The large mountain, Hadley Delta, rises about 11,000 feet above the nearby plain. The valley, Hadley Rille, is about one mile wide and 1,200 feet deep. Origin of the rille is a puzzle and its study is one of the objectives of this mission. (Artwork by Jerry Elmore.)

1 mile, a depth that varies generally from 600 to 900 feet but at the landing site is 1,200 feet, and is about 80 miles long. Such sinuous rilles are very common on the surface of the Moon. Their origin in general, and of Hadley Rille in particular, is very puzzling to lunar scientists and has been debated for many years. It has been attributed by various scientists to flowing water (although as a result of studying rocks returned on previous missions, we no longer believe this hypothesis), the flow of hot gases associated with volcanism, the flow of lava (in much the same way that lava flows down the sides of the Hawaiian volcanoes), and to collapsed lava tubes. Today, most scientists agree that the origin of such rilles is associated with fluid flow or with faulting. Yet we now know that water is generally absent from the Moon and probably never existed there in large quantities. The visit by the Apollo 15 crew to Hadley Rille will undoubtedly shed some light on the origin of rilles.

The approximate slope of the sides of Hadley Rille, near the landing site, is about 25 degrees. The depth is about 1,200 feet. Many fresh outcrops of rock that are apparently layered are seen along and just below the rille rim. The layers probably represent lava flows. Many large blocks have rolled downslope to settle on the floor of the rille. An analogous terrestrial feature that clearly has its origin in the flow of water is seen in figure 11, the Rio Grande Gorge near Taos, New Mexico. An important part of the Apollo 15 astronauts' training was a study for two days of this feature.

Examination of the rille floor and sampling of the rocks located there would be extremely valuable. Evidence on the origin of the rille would almost certainly be found. But perhaps more im-

portantly, rocks from a depth of about 1,200 feet would be collected. The study of the vertical changes in rocks, termed stratigraphy, provides the basic data necessary to construct the history of the Moon. (For example, many facts about the geological history of the Earth have been read from the rocks exposed in the walls and bottom of the Grand Canyon.) The scientific need to examine rocks from the bottom of the rille is so great that many people have tried to solve the problem of how to get them. One prominent scientist suggested that the astronauts use a crossbow with string attached to the arrow for retrieval. Of course the arrow would have been modified so that it adhered to rocks in some way rather than pierce them. This idea, as well as others, was abandoned because it was not practical. Even though access to the rille floor is not possible, sampling of the rocks that occur along the rim and photographing the walls are planned and may aid lunar scientists in determining the origin of rilles.

SECONDARY CRATER CLUSTER

A group of craters, labeled "South Cluster" on figure 16, will be observed and photographed during the second EVA. This group or cluster of craters is thought to have formed from impact of a group of objects that struck the Moon at the same time. Those objects were, in turn, thrown out from some other spot on the Moon by the impact of a single object from space. Hence the term secondary impact crater is applied to such craters.

Because the objects that created secondary impact craters came from some other spot on the Moon, the rock samples collected from such features may include samples from other parts of the Moon, and perhaps from considerable distance. Most of the material present in the vicinity of the craters is undoubtedly the material that was present before the craters were formed. The exotic material, that which came from elsewhere, is probably quite rare and the amount present at any crater may be less than 1 part per 1,000. Only after extensive investigation of the samples back in the laboratory on Earth can we be reasonably sure about the origin of a particular sample. Some lunar scientists believe that the objects that produced the South Cluster craters came from the very large crater Autolycus, situated about 100 miles to the northwest.

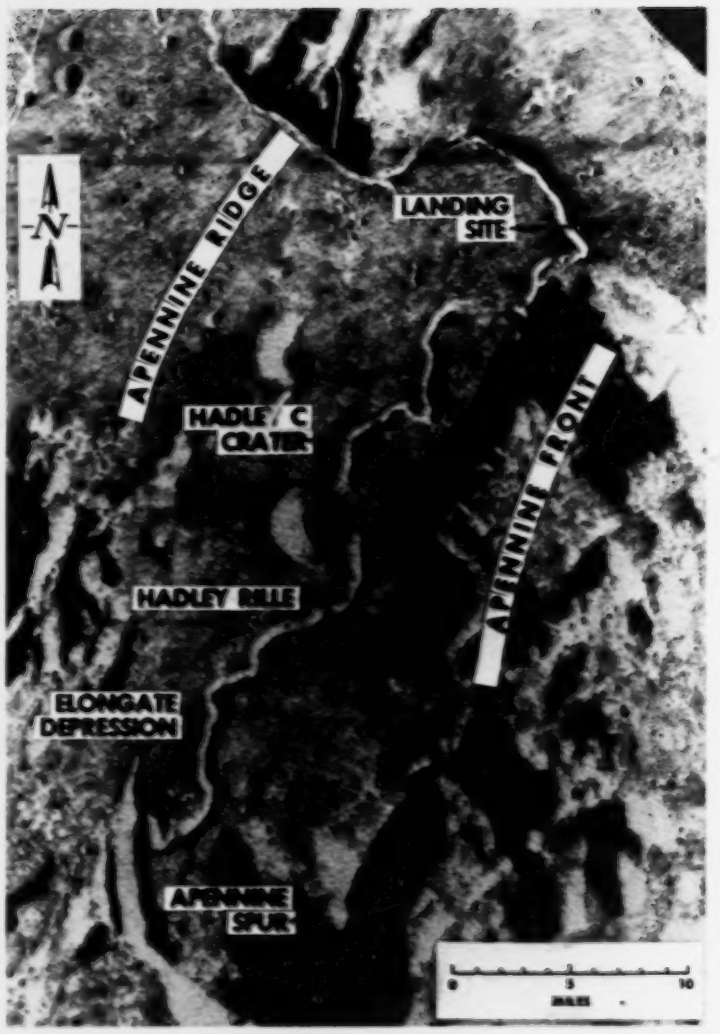

FIGURE 8.—General geography of the Apennine-Hadley landing site. Note that Hadley Rille is about 80 miles long.

An additional reason for collecting rocks in, or near, craters is that the impact, in forming the crater, always exhumes rocks from the bottom of the crater. Therefore the material that surrounds a crater includes material that originally was located at the bottom of the crater, at the top, and at all intermediate depths. If the material changes within the depth of the crater, then a study of the rock samples will very likely indicate that change.

Thus, for these two reasons, that we may sample distant localities and that we may see changes in the rocks with depth, the collection of samples at South Cluster is an important objective of the Apollo 15 mission.

NORTH COMPLEX

Not all features on the Moon's surface were formed by impacting objects. Some were formed

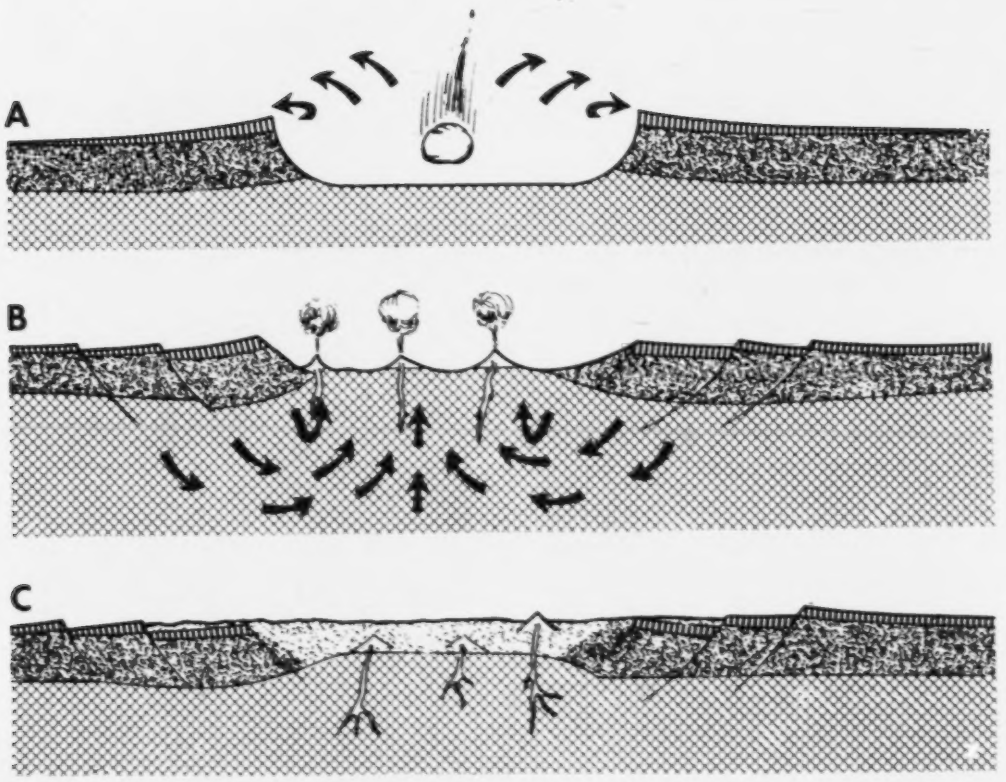

FIGURE 9.—Possible explanation of the origin of large basins on the Moon. In A, impact of an object from space, a large meteorite, created a hole and splashed material great distances. Some rocks were thrown hundreds of miles. The presence of the hole and the high temperatures generated by the heat from the impact create volcanoes. Material is transported to the surface of the basin. In the final stage, Part C, the basin has been largely filled again but with less dense rock at the surface. This explanation was suggested originally by Professor Donald Wise.

by internal processes. It is never easy on the basis of photographs or telescopic observations to distinguish between an internal and an external origin for a particular feature. In fact Galileo, the first man to look at the Moon through a telescope, about 300 years ago, suggested that all the craters on the Moon were due to volcanoes. His hypothesis stood unchallenged for two centuries until someone suggested the impact hypothesis. As so often happens in science, long, and sometimes bitter, arguments over which hypothesis was correct raged for about 100 years. Today, we believe that most lunar features have resulted from impacts but some have been caused by internal processes.

The features in the North Complex appear to have resulted from internal processes. Apollo 15 will give us the first opportunity to study at first hand the form of such features and the nature of their rocks and soils.

FIGURE 10.—Meteor crater. This crater, about a half mile across, 600 feet deep, and located near Flagstaff, Arizona, was caused by the impact of a large meteorite with the Earth in prehistoric times. Thousands of pieces of the meteorite have been found in the surrounding area. This feature has been studied extensively by members of the U.S. Geological Survey and has shed light on the details of crater formation. Note the raised rim, a characteristic of many lunar craters. The crater, readily accessible by automobile, is well worth the small time required to visit if one is nearby. Photo courtesy of U.S. Geological Survey.

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FIGURE 11.—A terrestrial model of Hadley Rille. The astronauts study the Rio Grande Gorge, near Taos, New Mexico, in preparation for their study of Hadley Rille. Shapes of the two features are similar and the rocks may possibly be similar but the origins of the two features are almost certainly different. During field training exercises, both Scott and Irwin shown here, carried mocked-up PLSS's.

Lunar Roving Vehicle

Inside the LM the astronauts will take with them to the surface a four-wheeled vehicle that can be used to transport themselves and equipment over the lunar surface. It is termed the Lunar Roving Vehicle (LRV) or Rover (figure 12). It is powered by two silver-zinc, 36-volt batteries and has an individual electric motor for each of the four wheels. An early version of the Rover, used for astronaut training, is shown in figure 13. The Rover deployment scheme is shown in figure 14. There is a navigation system that contains a directional gyroscope and provides information as to distance traversed as well as heading. In addition to the astronaut's oral descriptions, television pictures are telemetered back to Mission Control in Houston from the Rover. These pictures will be shown over the commercial TV networks.

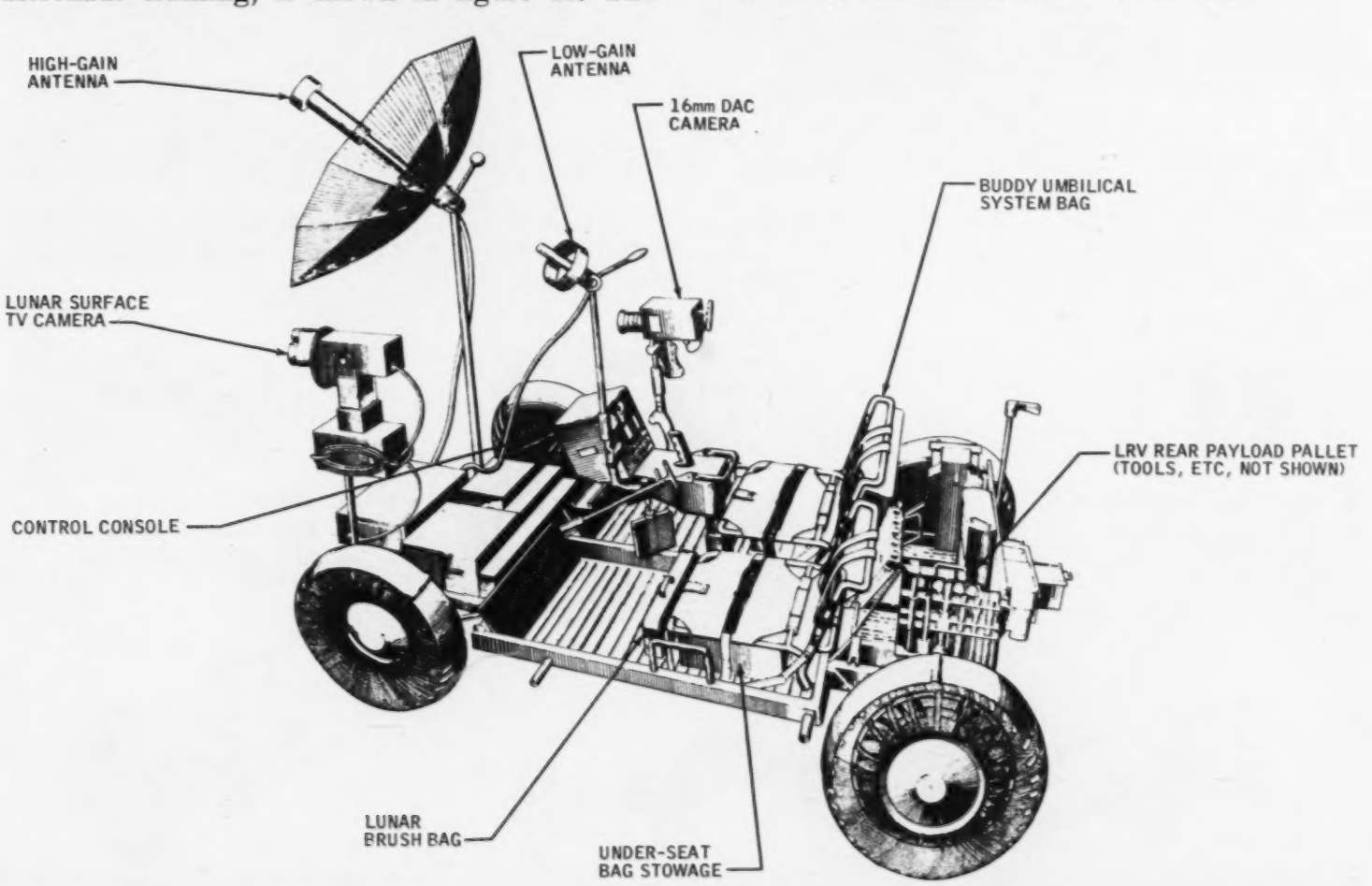


FIGURE 12.—The lunar Rover. Both astronauts sit in seats with safety seat belts. About 7 minutes are require to fully deploy Rover. The capacity of the Rover is 970 pounds. The vehicle will travel about 10 miles per hour on level ground. The steps necessary to remove it from the LM and to ready it for use are shown in Figure 14.

FIGURE 13.—This model of the lunar Rover, nicknamed "Grover", was used in astronaut training exercises. The canyon in the background is the Rio Grande Gorge, a natural terrestrial model of Hadley Rille, near Taos, New Mexico. Shown on Grover are Irwin and Scott, the "surface" astronauts of Apollo 15.

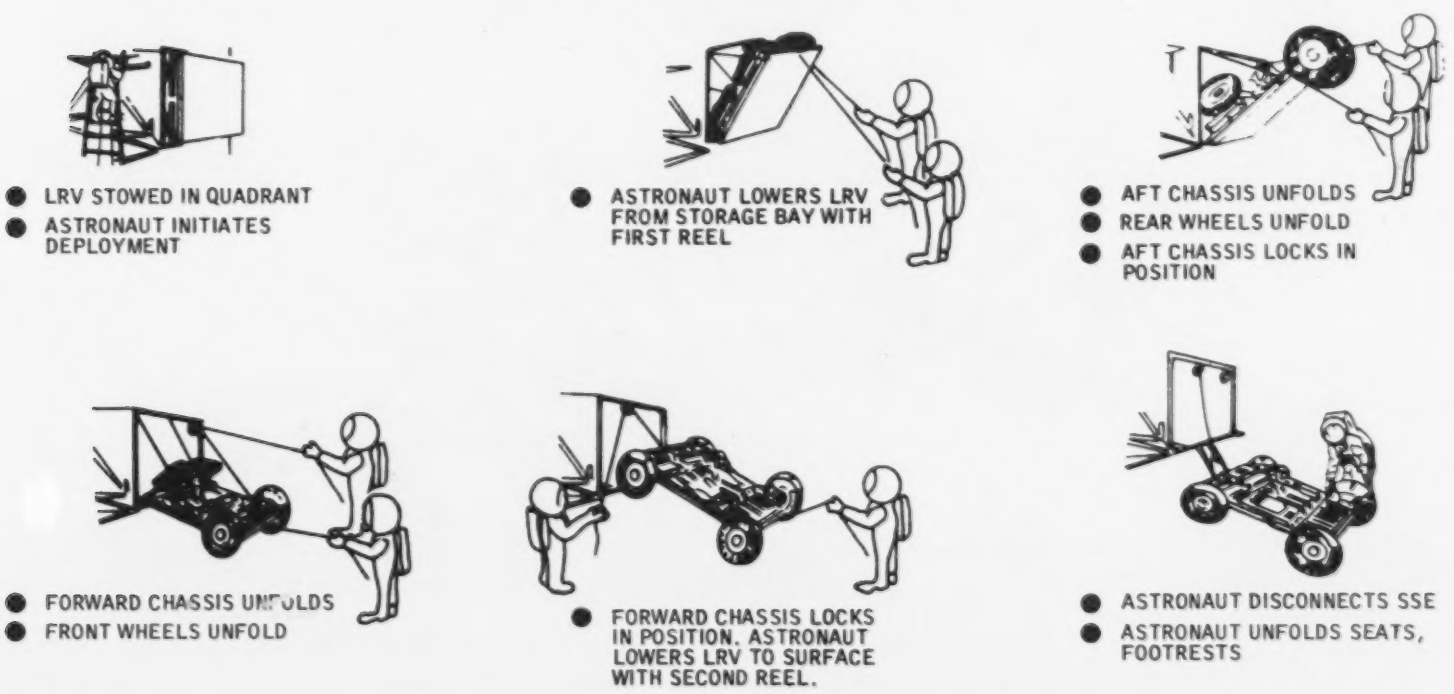

LRV STOWED IN QUADRANT
ASTRONAUT INITIATES DEPLOYMENT
ASTRONAUT LOWERS LRV FROM STORAGE BAY WITH FIRST REEL
AFT CHASSIS UNFOLDS
REAR WHEELS UNFOLD
AFT CHASSIS LOCKS IN POSITION
FORWARD CHASSIS UNFOLDS
FRONT WHEELS UNFOLD
FORWARD CHASSIS LOCKS IN POSITION. ASTRONAUT LOWERS LRV TO SURFACE WITH SECOND REEL.
ASTRONAUT DISCONNECTS SSE
ASTRONAUT UNFOLDS SEATS, FOOTRESTS

FIGURE 14.—Deployment sequence for the Lunar Roving Vehicle.

Surface Science Activities

Each of the two astronauts that descend to the lunar surface in the LM will spend about 20 hours in three periods of 7, 7, and 6 hours outside the LM working on the lunar surface. Most of that time will be used to study geological features, collect and document samples of rocks and soil, and set up several experiments that will be left behind on the lunar surface when the astronauts return to Earth.

The surface traverses described in this guidebook, which was written about 3 months before launch, should be considered as general guides for the astronauts to follow. From previous Apollo missions, we have learned that although some minor changes in plans are likely to occur, major changes are unlikely. On each mission a few changes were made by the crew because of unforeseen conditions. Instructions to the astronauts have always been "to use their heads" in following the detailed plans and this mission is no exception. In addition, the astronauts may consult over the radio with a group of scientists located in Mission Control at Houston and decide during the mission to make some changes. Undoubtedly, some details of the traverses will change. Equipment changes, on the other hand, are very unlikely to occur because all of the equipment has been built and is now being stowed in the spacecraft.

TRAVERSE DESCRIPTIONS

The planned Rover traverses are shown in figures 15 and 16. The activities at each of the stops

FIGURE 15.—The traverses planned for use with the Lunar Roving Vehicle. The Roman numerals indicate the three EVA's. The numbers are station stops. The station stops are keyed to the information given in Table 2. These same traverses are shown in figure 16, an overhead view of the landing site.

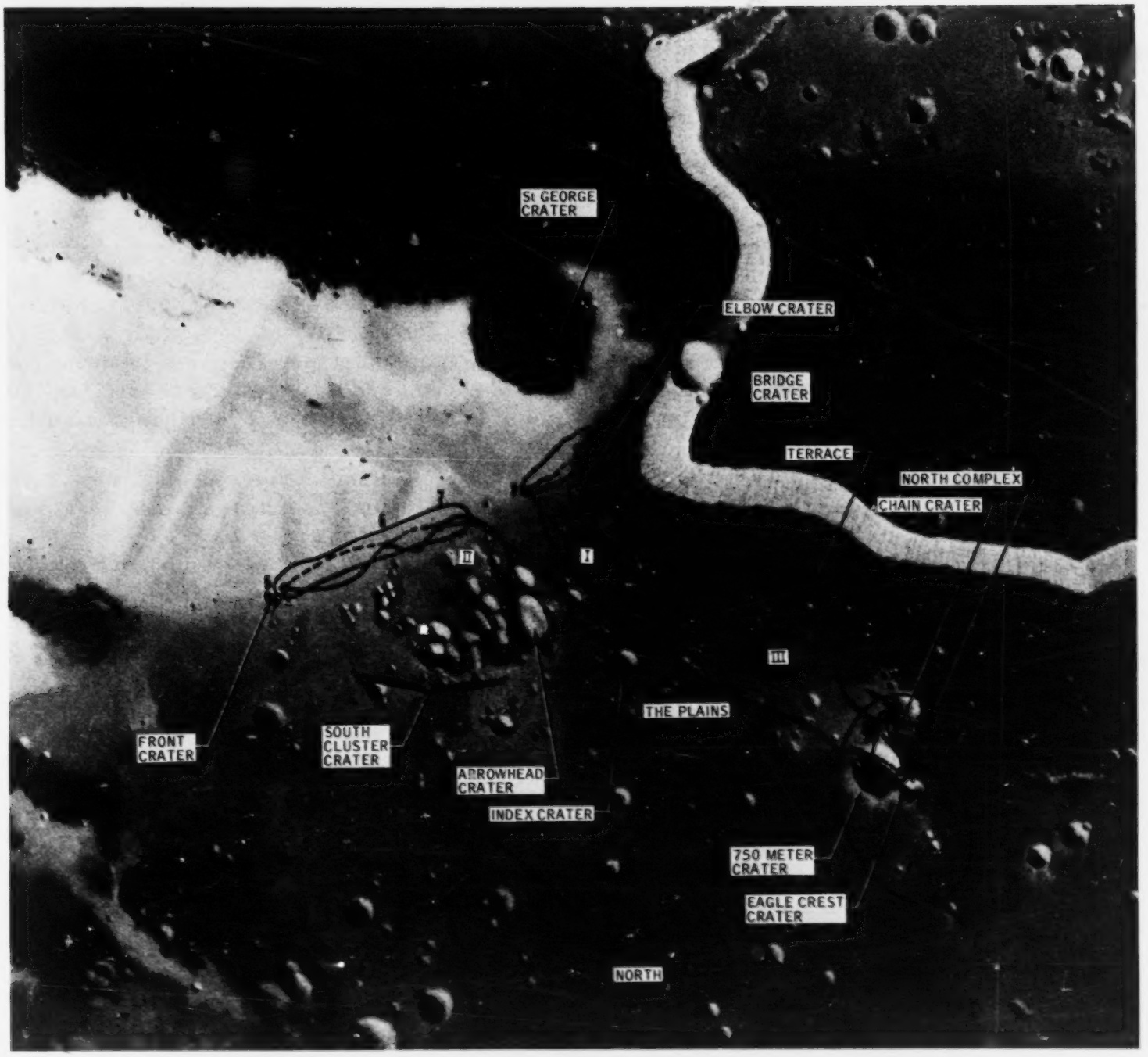


FIGURE 16.—Rover traverses. See explanation of Figure 15.

on all three traverses and along each traverse between stops are shown in Table 2. In order to use Table 2 effectively, the reader must have scanned most of the next section, "Surface Scientific Experiments and Hardware", and to have read the section "Lunar Geology Experiment".

The numbers assigned to each of the traverse stations shown in the figures and tables of this guidebook will not change. However, extra stations may be added before, as well as during, the mission. These extra stations will be termed "supplementary sample stations" to avoid confusing them with the existing stations.

In the event that the Rover becomes inoperative sometime during the mission, a series of walking traverses has been planned. (Figure 17.)

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND HARDWARE

In addition to the observations made by the astronauts and the collection of samples of lunar material to be returned to Earth, several scientific experiments will be set out by the astronauts on the lunar surface. The equipment for these experiments will remain behind on the Moon after the

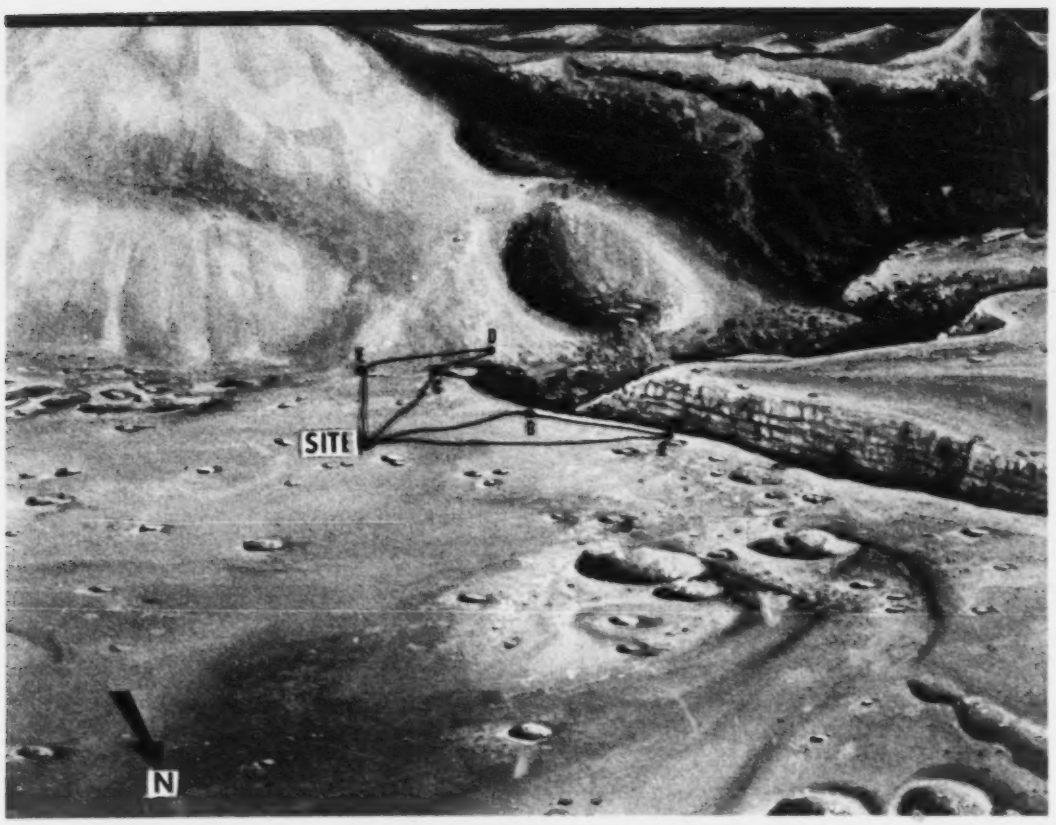


FIGURE 17.—Walking traverses. These alternate traverses can be done on foot. They will be used if the Rover becomes inoperative.

astronauts return to Earth. Data from these experiments will be sent to Earth over microwave radio links, similar to the ones used extensively for communications on Earth.

Apollo Lunar Surface Experiments Package (ALSEP)

Several of these experiments are a part of the Apollo Lunar Surface Experiments Package (ALSEP). General layout of the equipment on the lunar surface is shown in figure 18. A photograph of the Apollo 14 ALSEP is shown in figure 19. The ALSEP central station, figure 20, although obviously not an experiment, provides radio communications with the Earth and a means for control of the various experiments. The experiments connected electrically to the central station are the Passive Seismic Experiment, the Lunar Surface Magnetometer, the Solar Wind Spectrometer, Suprathermal Ion Detector, Heat Flow Experiment, Cold Cathode Ion Gauge, and Lunar Dust Detector. I discuss briefly each of these experiments.

Electrical power for the experiments on the lunar surface is provided by the decay of radioisotopes in a device termed Radioisotope Thermoelectric Generator (RTG), shown in figure 21. A total of roughly 70 watts is delivered. Let me draw special attention to this power of 70 watts. It is truly incredible that all of the experiments together use approximately the amount of power that is consumed by an ordinary 75 watt light bulb! The electrical wires are flat, ribbon-like cables that may be seen in figure 19. The RTG is filled with fuel after the astronauts place it on the lunar surface.

During EVA 1, the astronauts remove the ALSEP equipment from the LM, carry it to a site at least 300 feet from the LM, and place it on the lunar surface. A summary of these ALSEP operations is given in Table 3. A list of the principal investigators and their institutions is included in Table 4.

Heat Flow Experiment (HFE)

Heat flows from hot regions to cold regions. There is no known exception to this most general law of nature. We are certain that the interior of the Moon is warm. It may be hot. Therefore heat flows from the interior of the Moon to the surface

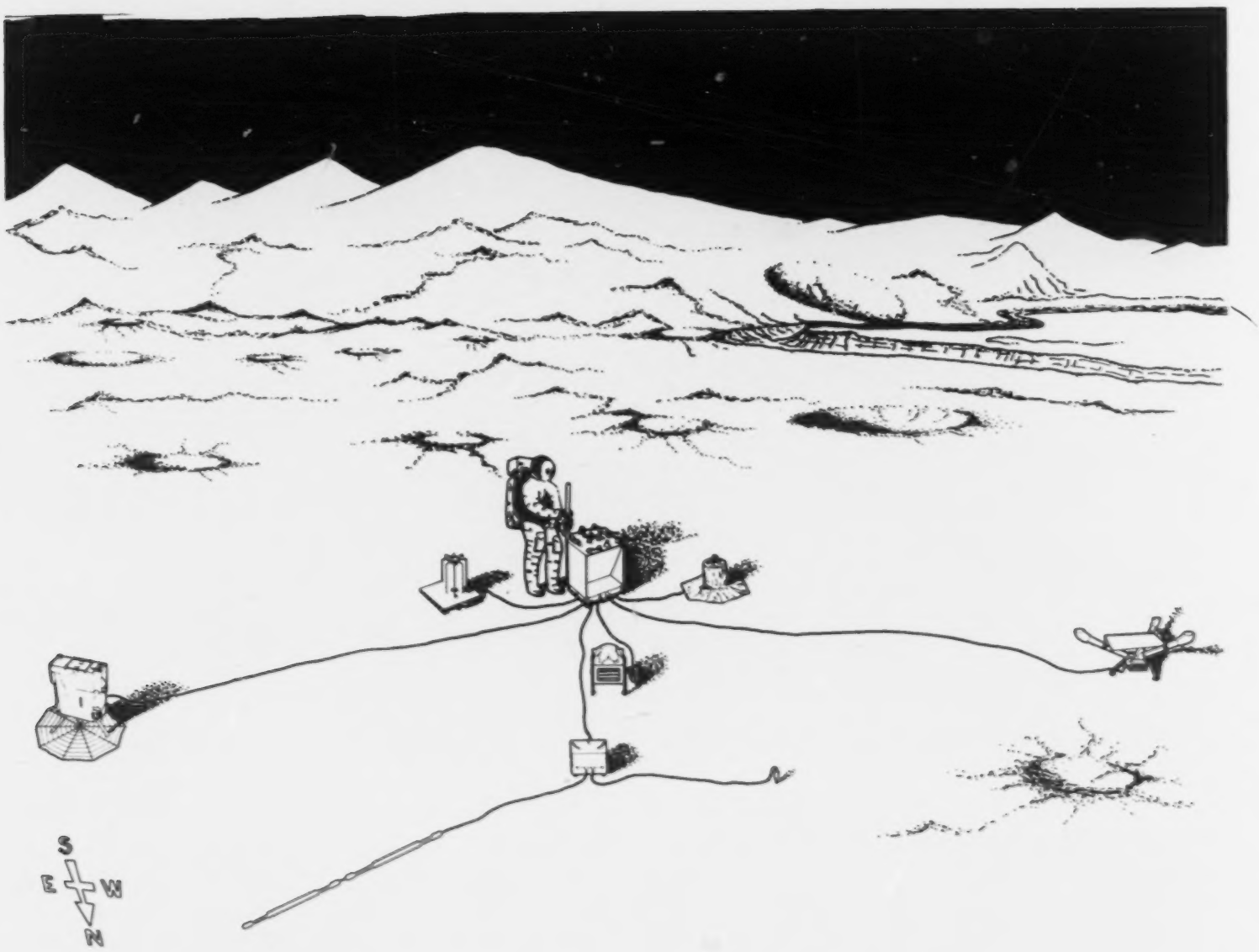


FIGURE 18.—General layout of the ALSEP. The sizes of the astronaut, equipment, and lunar features are drawn to different scales. Locations are shown in true relation to the surface features of the Moon.

where it is then lost into cold space by radiation. It is the function of the Heat Flow Experiment (HFE) to measure the amount of heat flowing to the surface at the Hadley-Apennine site.

At the present time, the heat flowing to the surface of the Moon from the interior has been produced mostly by decay of the natural radioactive elements thorium, uranium, and potassium. Measurements made directly on the lunar samples returned to Earth by Apollo 11, 12, and 14 have revealed the presence of significant amounts of these elements. The normal spontaneous decay of these elements into other elements slowly releases energy. The decay process is similar to that used in nuclear reactors on Earth to generate electrical power from uranium. In the Moon, most of the energy appears in the form of heat which raises the temperature of the interior of the Moon.

In addition to the amount of radioactive material present, the internal temperature of the Moon depends on other parameters. The thermal properties of lunar rocks are equally important. The thermal conductivity of a material is a measure of the relative ease with which thermal energy flows through it. Rather well-known is the fact that metals are good conductors and that fiberglass, asbestos, and bricks are poor conductors. Most of us would never build a refrigerator with copper as the insulation. Values of the thermal properties of rocks are closer to the values of fiberglass than to those of copper and other metals. Rocks are fairly good insulators.

The Heat Flow Experiment has been designed to measure the rate of heat loss from the interior of the Moon. To obtain this measurement, two holes are to be drilled into the surface of the Moon

FIGURE 19.—Apollo 14 ALSEP. Individual items are readily identified by comparison with the sketches included in this guidebook.

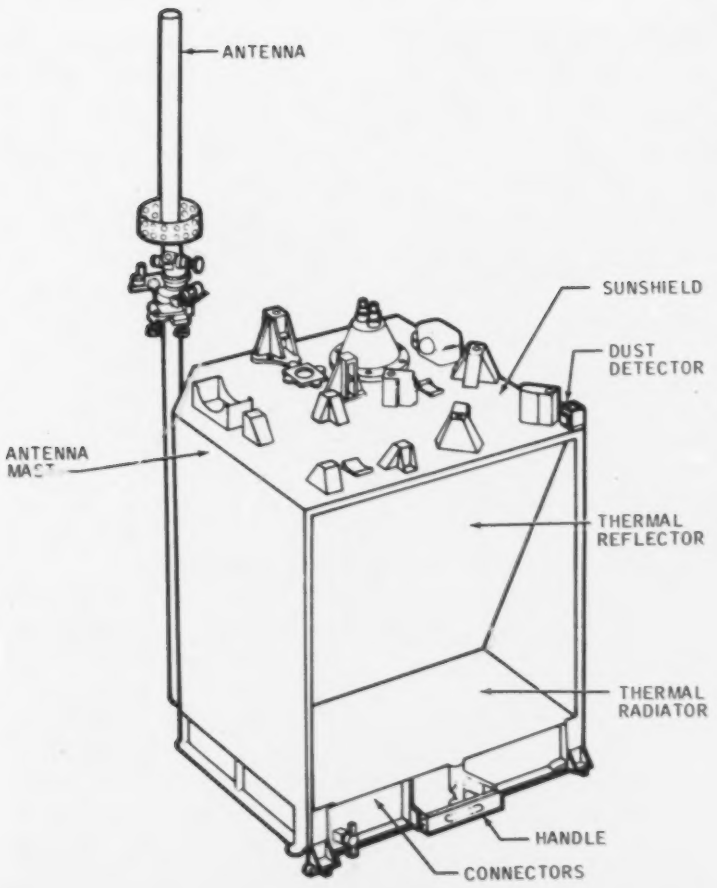


FIGURE 20.—The ALSEP central station. This equipment is connected electrically to each of the other ALSEP experiments. It is a maze of electronics that accepts the electrical signals from various experiments and converts them into a form suitable for transmission by radio back to the Earth. The pole-like feature on top of the central station is a high-gain antenna. It is pointed towards the Earth. Commands may be sent from the Earth to the central station to accomplish various electronic tasks.

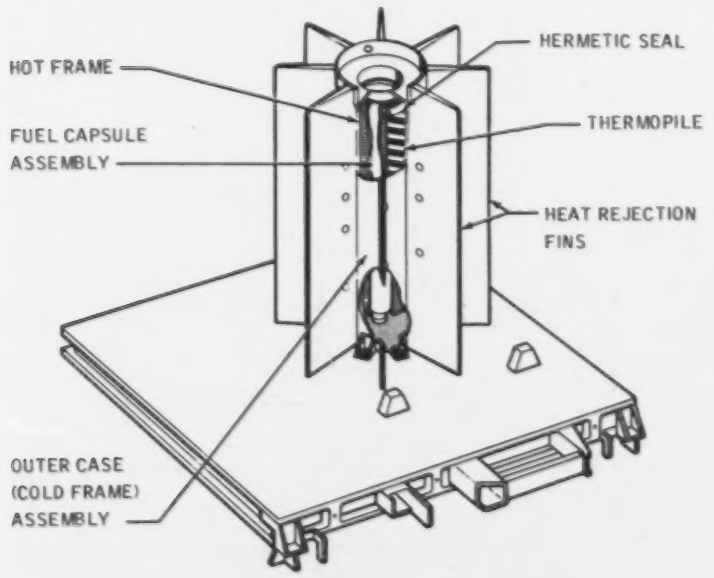


FIGURE 21.—Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts.

by one of the astronauts to a depth of about 10 feet by means of the drill sketched in figure 22. After each hole is drilled, temperature sensors (platinum resistance thermometers) are placed at several points in the lower parts of the holes and several thermocouples (for measuring temperatures with lower precision) are placed in the upper portions of the holes. See figure 23. The thermal properties of the rocks will be measured by the equipment that is placed in the hole, they will also be measured on samples that are returned to the Earth.

Because the temperature of the rock is disturbed by the drilling process, the various measurements for heat flow will be taken at regular intervals over several months. As the residual heat left around the hole from drilling dissipates with time, the temperatures measured in the experiment will approach equilibrium.

The great importance of the HFE derives from the fact that knowledge of the amount of heat flowing from the interior of the Moon will be used

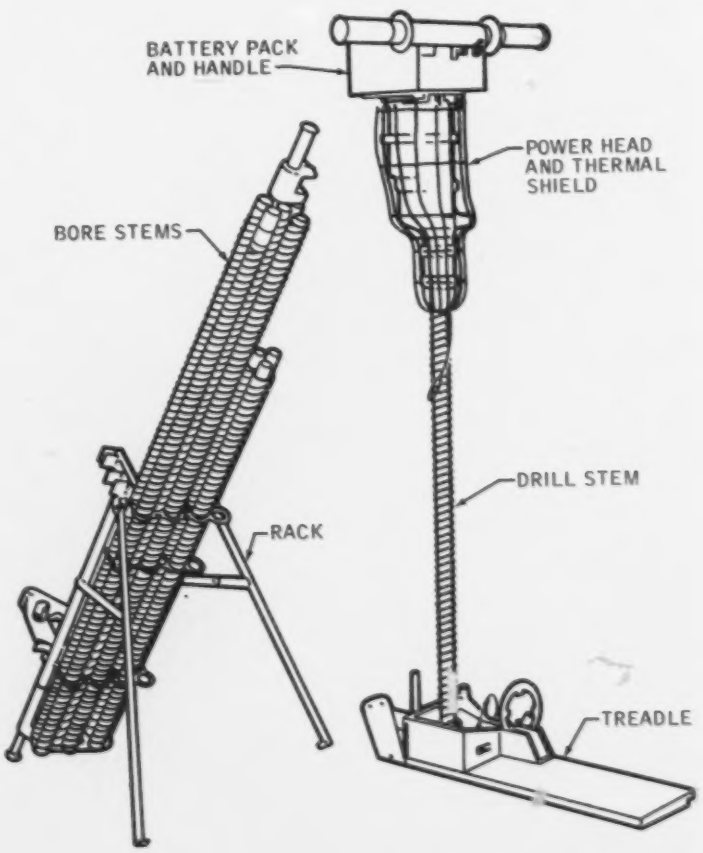


FIGURE 22.—Lunar Surface Drill. This drill will be used to drill holes on the Moon to a depth of about 10 feet. It is electrically powered and operates from batteries. The treadle is used to steady the drill stem and to deflect cuttings from striking the astronaut. Two holes are used for the heat flow experiment and a third one is used to obtain samples for study back on Earth.

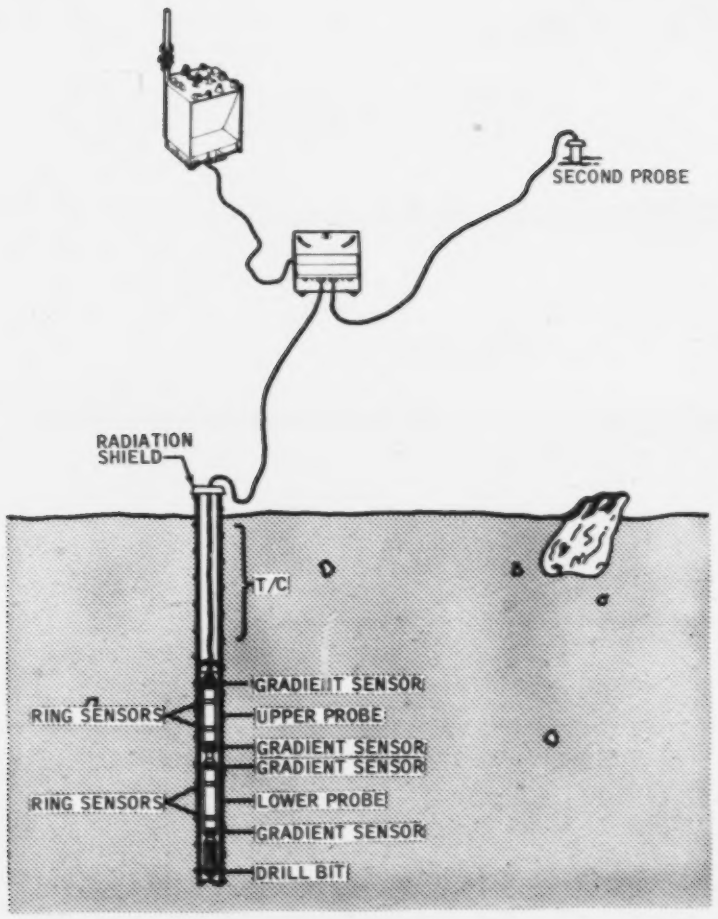


FIGURE 23.—Heat Flow Experiment. Probes are placed in two holes drilled in the lunar surface with the drill shown in figure 22. One hole is shown in the figure as a section to show the various parts. The gradient is the difference of temperature at two points divided by the distance between the points. Heat flow is measured by measuring the gradient and independently measuring the thermal conductivity; heat flow is the product of gradient and thermal conductivity. The symbol T/C indicates thermocouples that are present in the upper part of the holes.

to set limits on the amount of radioactivity now present in the Moon and to set limits on models of the thermal history of the Moon.

Passive Seismic Experiment (PSE)

The Passive Seismic Experiment (PSE) is used to measure extremely small vibrations of the Moon's surface. It is similar to seismometers used on the Earth to study the vibrations caused by earthquakes and by man-made explosions. The PSE equipment is seen in figure 24. The principle of operation is indicated in figure 25. As the instrument is shaken, the inertia of the mass causes the boom to move relative to the case. This relative motion is detected electrically by the capacitor and

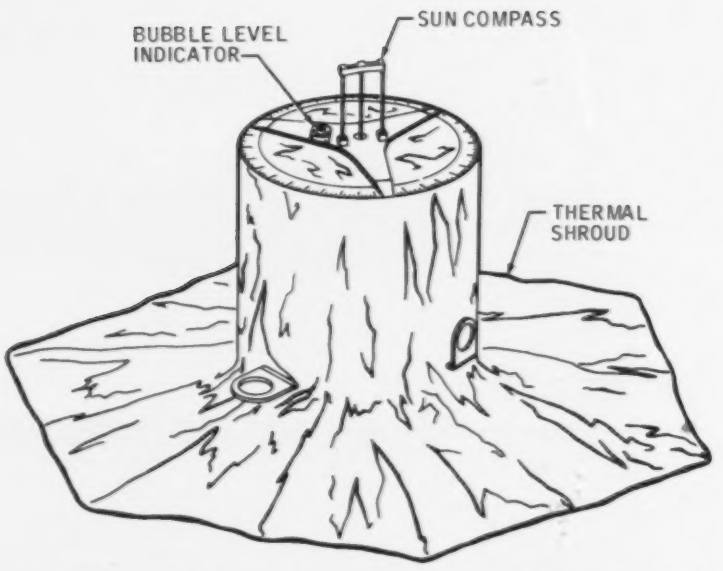


FIGURE 24.—Passive Seismometer. The instrument is covered with a blanket of superinsulation to protect it from the extreme variations of temperature on the Moon (−400° to +200°F). The principle of operation is shown in figure 25. The level, used on the Moon in exactly the same way as on the Earth, indicates whether the instrument is level. The Sun compass is used to indicate direction.

the electrical signal is then transmitted by radio to the Earth.

A typical seismic signal for the Moon is seen in figure 26. Such signals are detected at the Apollo 12 and 14 sites at the rate of about one per day. There is usually increased activity when the Moon is farthest from the Earth and also when it is nearest the Earth.

The data from the PSE, in conjunction with similar data from Apollo 12 and 14 sites, are especially valuable. They will be used to study the nature of the interior the Moon, to determine the location of moonquakes and to detect the number and size of meteoroids that strike the lunar surface.

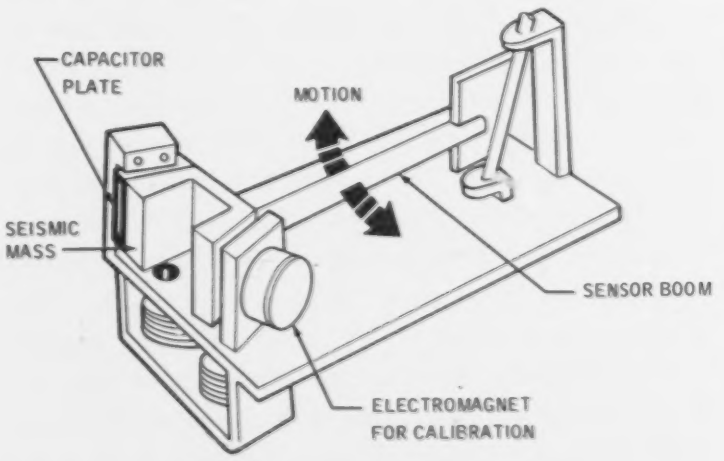


FIGURE 25.—Principle of operation of passive seismometer. See text for details.

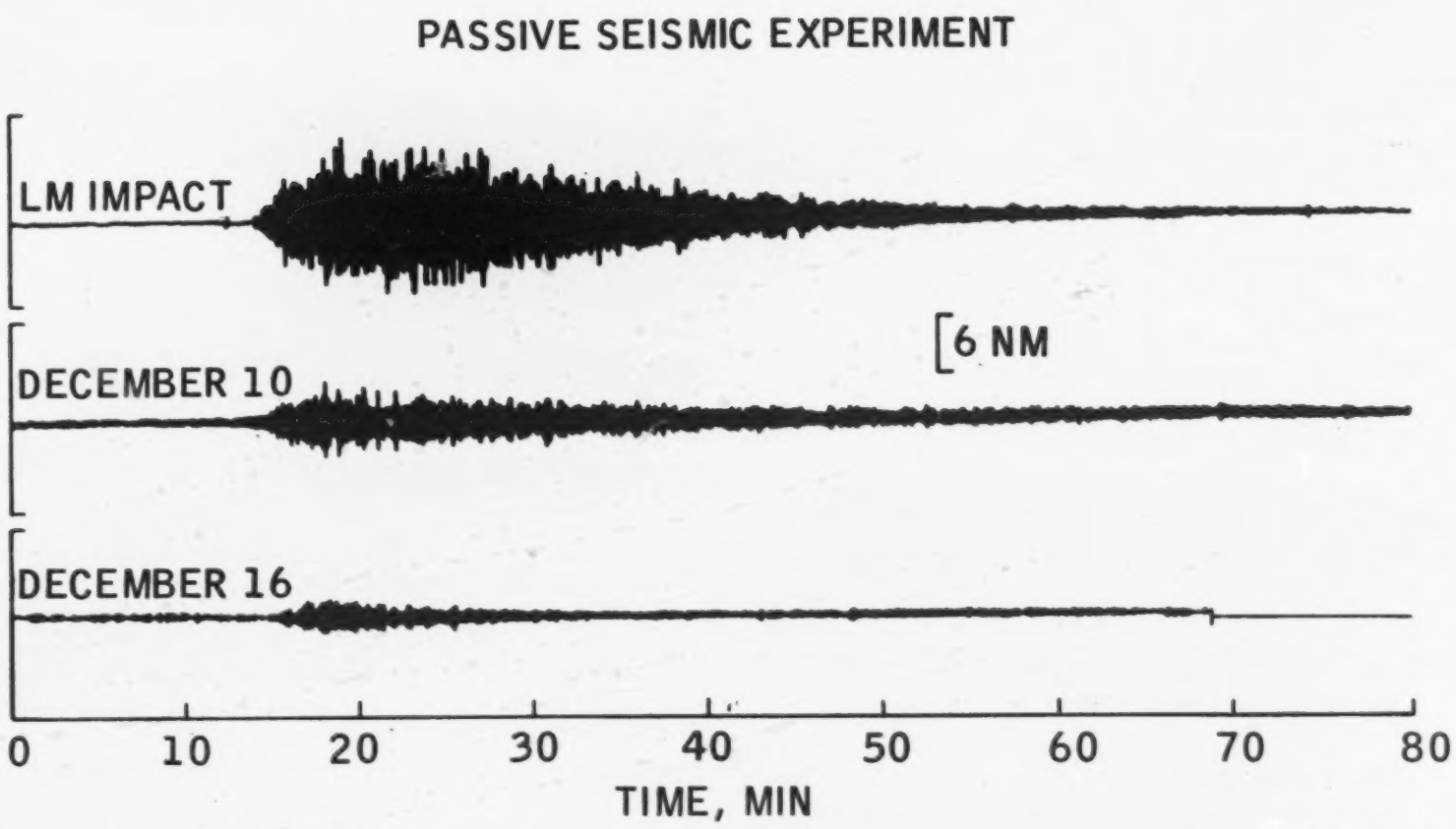


FIGURE 26.—Typical seismic signals for the Moon. These events were sensed at the Apollo 12 seismometer. To produce the largest signals shown here, the Moon's surface moved about 2 ten-thousandths of an inch.

The Moon is still being bombarded by small objects; most of them are microscopic in size. The Earth is also being bombarded but most small objects completely disintegrate in the Earth's atmosphere; they are the familiar shooting stars.

Lunar Surface Magnetometer (LSM)

The Lunar Surface Magnetometer (LSM) is used to measure the variations with time of the magnetic field at the surface of the Moon. A similar instrument was left at the Apollo 12 site. It is still sending data to Earth. None was left at the Apollo 14 site although two measurements of the magnetic field were made there with a smaller, portable magnetometer. The LSM equipment is shown in figure 27. Because the magnetic field at the surface of the Moon can change in amplitude, frequency, and direction, the LSM is used to measure the magnetic field in three directions. The sensors are located at the ends of three booms.

The magnetic field of the Moon (and also the Earth) has two parts, one that changes with time and one that is steady and does not change rapidly with time. The part that changes with time is caused by travelling electromagnetic waves.

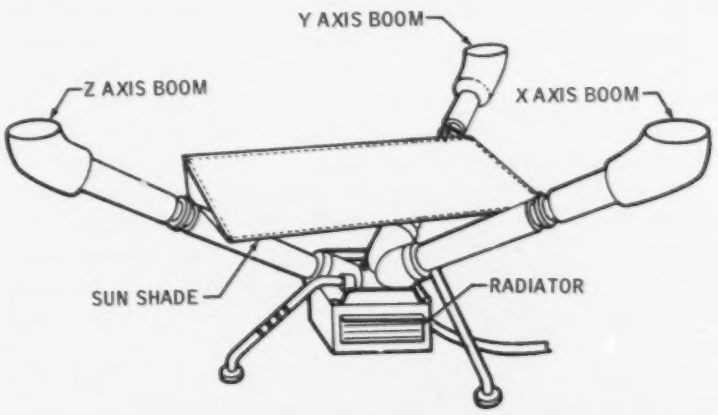


FIGURE 27.—Lunar Surface Magnetometer. Measurements are obtained as a function of time of the magnetic field at the surface of the Moon by the lunar surface magnetometer. The actual sensors are located in the enlarged parts at the end of the three booms. The plate located in the center of the instrument is a sun shade to protect the electronics in the box at the junction of the three booms from direct sunlight.

The steady part of the Earth's magnetic field, that part which does not change rapidly with time, is about 50,000 gamma (the usual unit of magnetic field employed by Earth scientists). It causes compasses to point approximately north-south. The steady part of the lunar magnetic field measured at the Apollo 12 site, was about 35 gamma, somewhat more than 1,000 times smaller than the

Earth's field. Yet the 35 gamma field was several times larger than we had expected. Similar measurements obtained at the Apollo 14 site with the smaller portable magnetometer revealed a magnetic field in two different spots of about 65 gamma and 100 gamma. The steady part of the lunar magnetic field is undoubtedly due to the presence of natural magnetism in lunar rocks. The natural magnetism was probably inherited early in the Moon's history (perhaps several billion years ago) when the Moon's magnetic field was many times larger than today.

The LSM is also used to measure the variation with time of the magnetic field at the surface of the Moon. The variations are caused by electromagnetic waves that emanate from the Sun and propagate through space. The largest change in the magnetic field ever measured in space, about 100 gammas, was detected by the Apollo 12 LSM.

Variations with time in the magnetic field at the surface of the Moon are influenced greatly by the electrical properties of the interior of the Moon. Therefore, a study of the variations with time of the magnetic field will reveal the electrical properties of the Moon as a function of depth. Because the electrical properties of rocks are influenced by the temperature, we hope to use the data from the LSM to measure indirectly temperatures in the interior of the Moon.

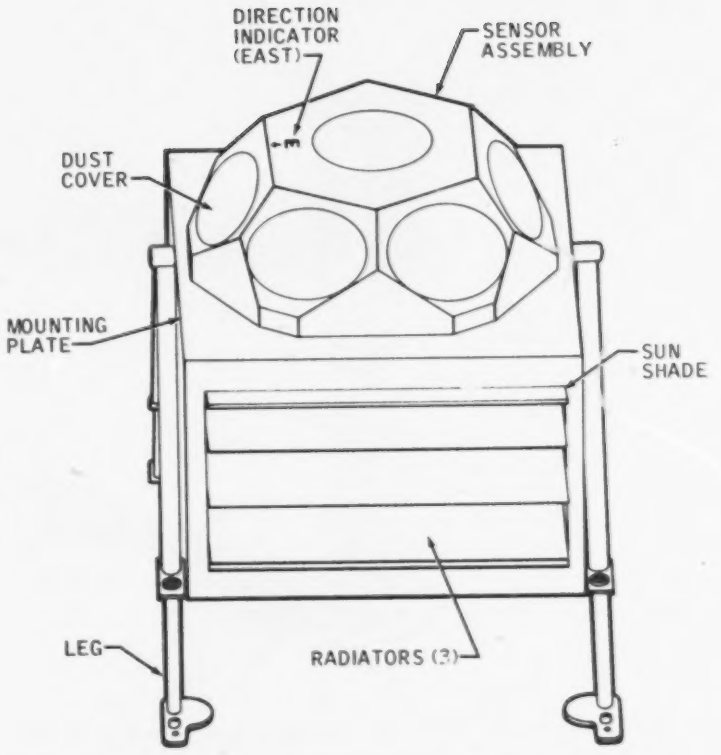


FIGURE 28.—Solar Wind Spectrometer. With this instrument, the solar wind will be studied. It measures energy, density, directions of travel, and the variations with time of the solar wind that strikes the surface of the Moon. During the journey to the Moon, this equipment is carried with the legs and sun shade folded so that it will occupy less space. The astronaut unfolds the legs and sun shade before setting it out on the Moon.

Lunar Atmosphere and Solar Wind Experiments

(1) *Solar Wind Spectrometer (SWS)*
(2) *Solar Wind Composition (SWC)*
(3) *Suprathermal Ion Detector (SIDE)/Cold Cathode Ion Gauge (CCIG)*

Matter is ejected, more or less continuously, by the Sun and spreads throughout the solar system. It is called the solar wind. It is very tenuous. It moves with a speed of a few hundred miles per second. The energy, density, direction of travel, and variations with time of the electrons and protons in the solar wind that strike the surface of the Moon will be measured by the Solar Wind Spectrometer. This equipment is shown in figure 28. The seven sensors are located beneath the seven dust shields seen in the picture. The data allow us to study the existence of the solar wind at the lunar surface, the general properties of the solar wind and its interaction with the Moon. The solar wind "blows" the Earth's magnetic field into the form of a long tail that extends past the Moon. Thus the SWS is also used to study the Earth's magnetic tail.

Some equipment carried to the Moon to determine the composition of the solar wind is extremely simple. The Solar Wind Composition (SWC) experiment is essentially a sheet of aluminum foil like the familiar household item used to wrap food. It is seen in figure 29. Exposed on the lunar surface to the solar wind, it traps in the foil the individual particles of the solar wind. The foil is returned to Earth and the individual elements are examined in the laboratory. Sponsored by the Swiss government, this experiment is international in scope.

Two experiments, the Suprathermal Ion Detector Experiment (SIDE) and the Cold Cathode Ion Gauge (CCIG) are used to measure the number and types of ions on the Moon. An ion is an electrically charged molecule. It may be either positive or negative, which depends on whether one or more electrons are lost or gained, respectively. Those ions on the Moon are chiefly hydrogen and helium and are largely derived from the solar wind

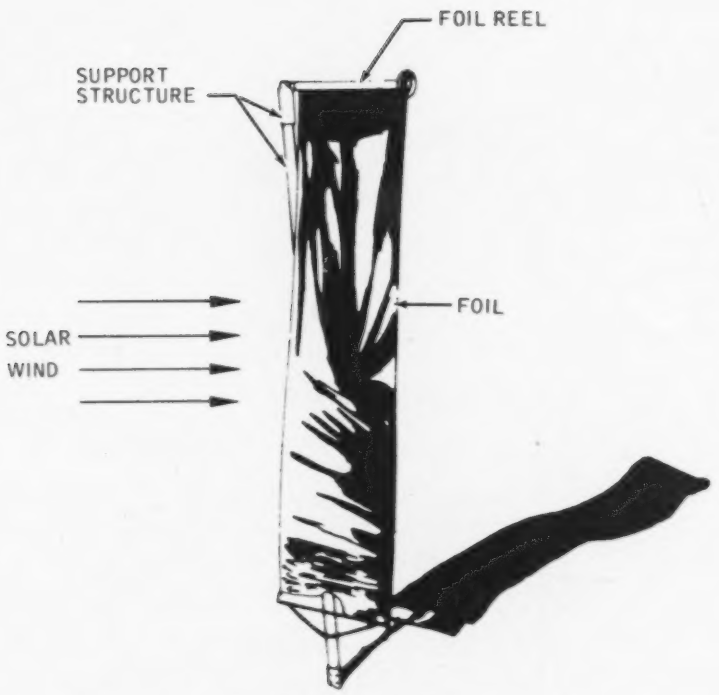


FIGURE 29.—Solar Wind Composition Experiment. Particles in the solar wind strike the aluminum foil, are trapped in it, and finally brought back to Earth by the astronauts for examination. This experiment is sponsored by the Swiss government.

but several others are present also. The hardware is illustrated in figure 30.

The SIDE is used to measure the flux, number, density, velocity, and the relative energy of the positive ions near the lunar surface. The CCIG, although a separate experiment, is electronically integrated with the SIDE. It is used to measure the pressure of the lunar atmosphere. It operates over the pressure range of 10^{-6} to 10^{-12} torr. (For comparison of these units, the Earth's atmosphere at sea level produces a pressure of about 760 torr and the pressure in the familiar Thermos vacuum bottles is about 10^{-3} torr.) The lowest pressures obtainable on Earth in vacuum chambers is about 10^{-13} torr. The pressure measured at the Apollo 14 site by CCIG was about 10^{-12} torr. At that pressure only 500,000 molecules of atmosphere would be present in a volume of 1 cubic inch. Although that number may seem like many molecules, remember that 10^{15} times as many exist in each cubic inch near the surface of the Earth! The lunar pressure varies slightly with time.

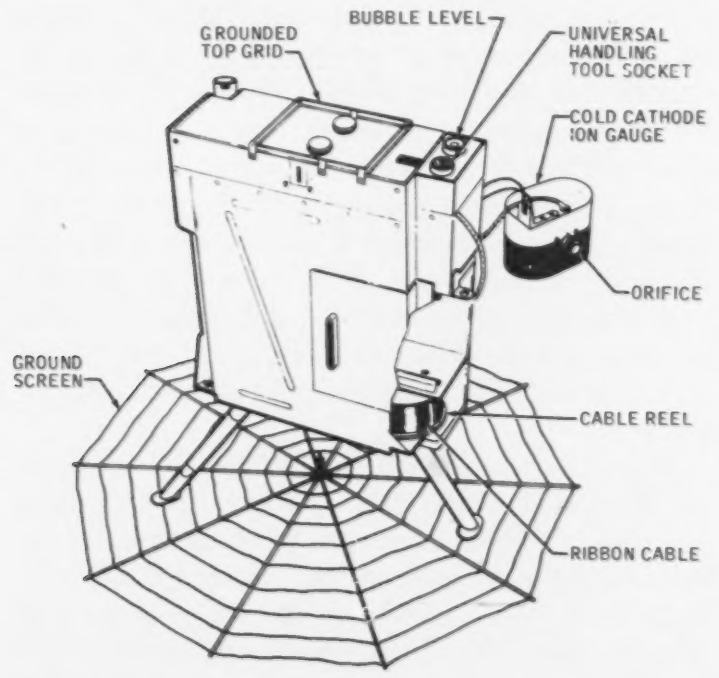


FIGURE 30.—Suprathermal Ion Detector (SIDE) and Cold Cathode Ion Gauge (CCIG). These two experiments are used to study the atmosphere of the Moon.

Astronauts continually release gas molecules from their suit and PLSS. The molecules are chiefly water and carbon dioxide. These additional molecules increase locally the atmospheric pressure and the CCIG readily shows the presence of an astronaut in the immediate vicinity. It is expected that the Apollo 14 CCIG will "see" the arrival of the Apollo 15 LM on the Moon from the exhaust gases.

Lunar Dust Detector (LDD)

The main purpose of the Lunar Dust Detector (LDD) is to measure the amount of dust accumulation on the surface of the Moon. It also measures incidentally the damage to solar cells caused by high energy radiation and it measures the reflected infrared energy and temperatures of the lunar surface. It is located on the ALSEP Central Station (see figure 20) and consists of three photocells.

Laser Ranging Retro-Reflector (LRRR)

The Laser Ranging Retro-Reflector (LRRR pronounced LR-cubed) is a very fancy mirror that is used to reflect light sent to the Moon by a laser. By measuring the time required for a pulse of light to travel from the Earth to the Moon, be reflected by the LRRR, and return to the Earth, the distance to that point on the Moon can be measured very precisely. Even though the distance to the Moon is about 240,000 miles, the exact distance can be measured with this technique with an accuracy of a few inches. Such data provide information about the motion of the Moon in space about the

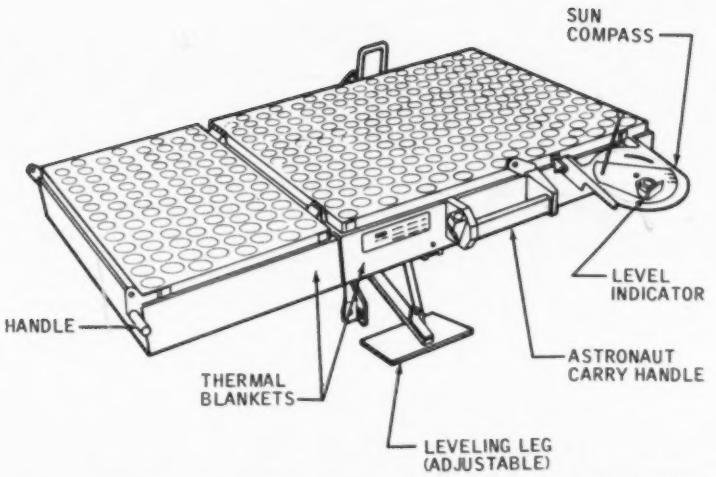


FIGURE 31.—Laser Ranging Retro-Reflector. A rather fancy mirror, the LRRR, is used to return to Earth a laser beam reflected at the surface of the Moon. There are no restrictions on its use by anyone throughout the world.

Earth, the vibrations of the Moon, and incidentally about the variations in the rotation of the Earth.

The LRRR equipment is shown in figure 31. It consists of 309 individual fused silica optical corner reflectors. Obviously, scientists in any country on Earth can use this equipment to return their own laser beams. Similar ones, though smaller, were left at the Apollo 11, 12, and 14 sites.

Lunar Geology Experiment (LGE)

Most of the time spent by the astronauts during the three EVA's will be devoted to investigation of various geologic features at the landing site and to collecting samples of rocks. Many detailed photographs will be obtained to supplement the verbal descriptions by the astronauts. Samples of the rocks present at the site will be bagged and brought back to Earth. The astronauts will use several individual pieces of equipment to help them with their tasks. In this section, I describe briefly the individual items used in studying the geology of the Hadley-Apennine region and in collecting samples for return to Earth.

Soon after the astronauts first set foot on the surface of the Moon, one will use the tool shown in figure 32 to collect a small (about 1–2 lbs.) sample of rock and soil. That sample is termed the contingency sample. It is stowed immediately on board the LM to insure that at least some material would be obtained in the unlikely event that the surface activities had to be terminated abruptly and prematurely for any reason.

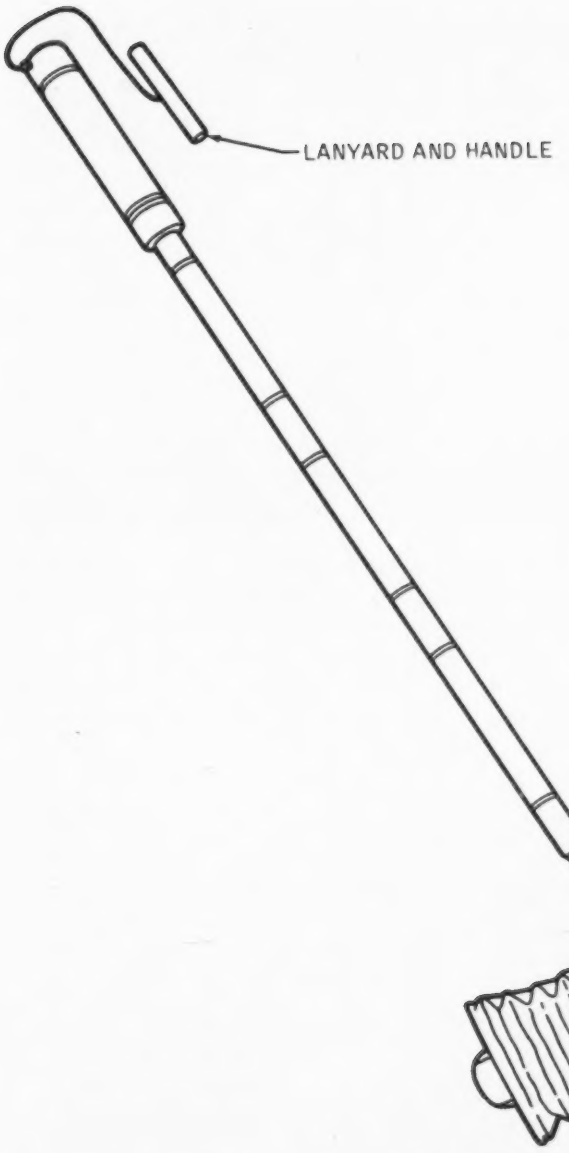


FIGURE 32.—Contingency Sampler. During the flight to the Moon, the handle is folded. Tension on the rope stiffens it so that the astronauts can scoop quickly a few rocks and some soil. The bag is made of Teflon, will hold about 2 pounds of rocks and soil, and is detached from the handle before stowage in the LM. This tool is used to collect material from the immediate area of the LM very soon after the astronauts first egress from the LM so that some samples will have been obtained if the surface activities must be curtailed and the mission aborted.

Observations made on the lunar surface of the various geological features are very important. The television camera allows us on Earth to follow the astronauts and to "see" some of the same features, though not nearly so well, as the astronauts see. The TV camera used on Apollo 14, similar to the one on this mission, is shown in figure 33. The Apollo 15 TV camera will be mounted on the Rover during the traverses.

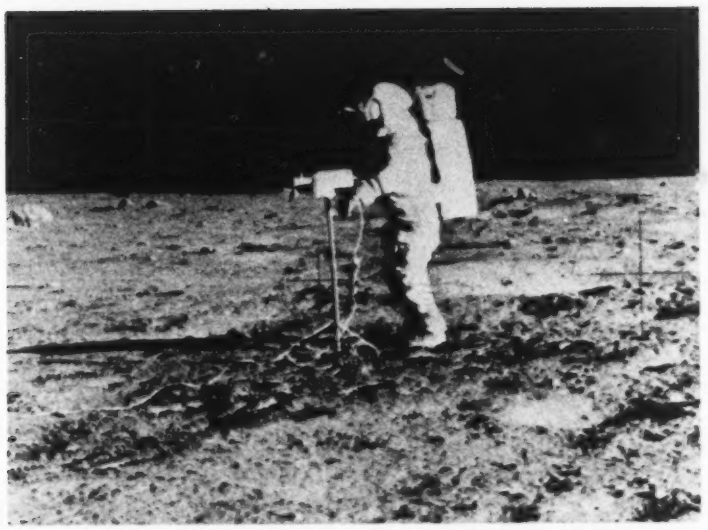


FIGURE 33.—Apollo 14 television camera. The astronaut is adjusting the TV camera to obtain the best possible viewing of activities around the LM during the Apollo 14 mission. A similar television camera will be carried aboard Apollo 15; it will be mounted sometimes on the Rover. Note the many craters in the foreground and the boulders in the distance.

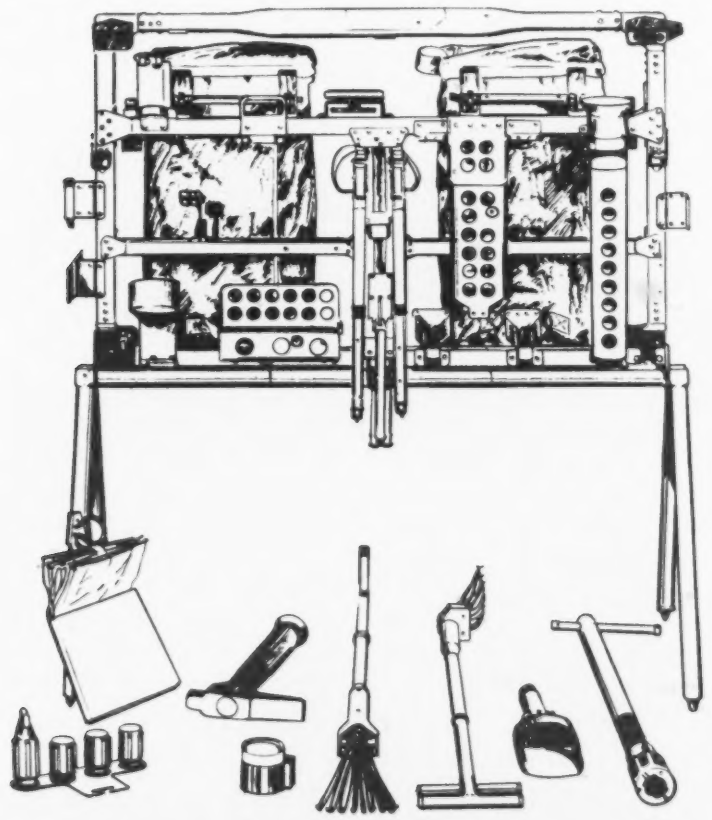


FIGURE 34.—Lunar Geological Hand Tools. This equipment is used to collect samples of rock and soil on the Moon. See text and subsequent figures for details.

Other tools used by the astronauts are shown in figure 34 together with an aluminum frame for carrying them. The hammer is used to drive core tubes into the soil, to break small pieces of rocks from larger ones, and in general for the same

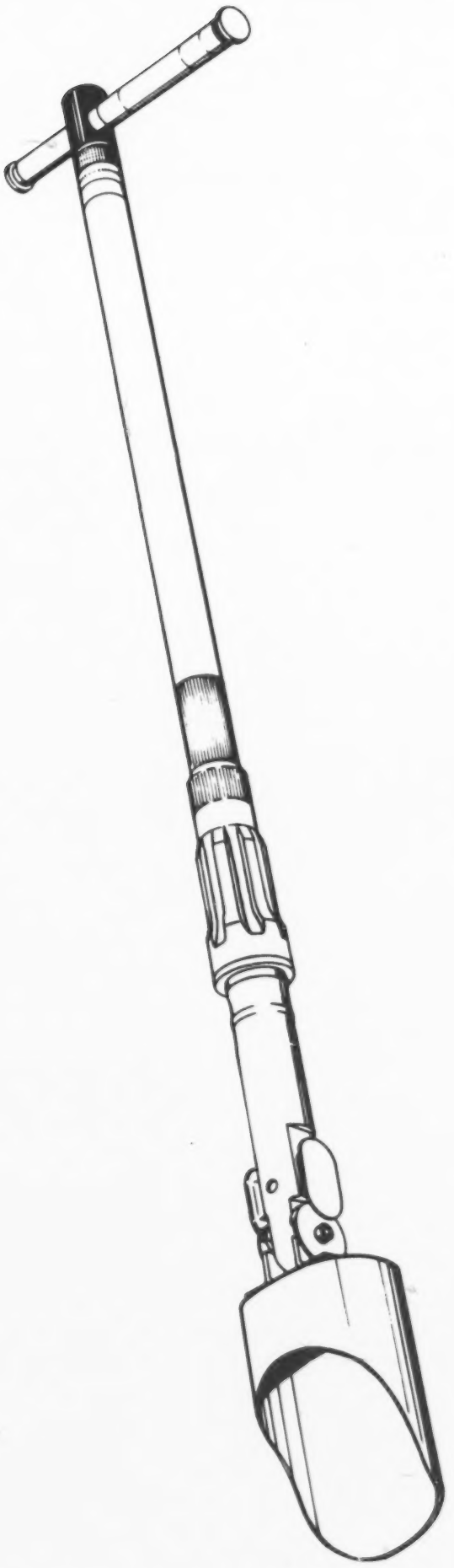


FIGURE 35.—Scoop with extension handle. Its use in Apollo 12 is shown in Figure 36.

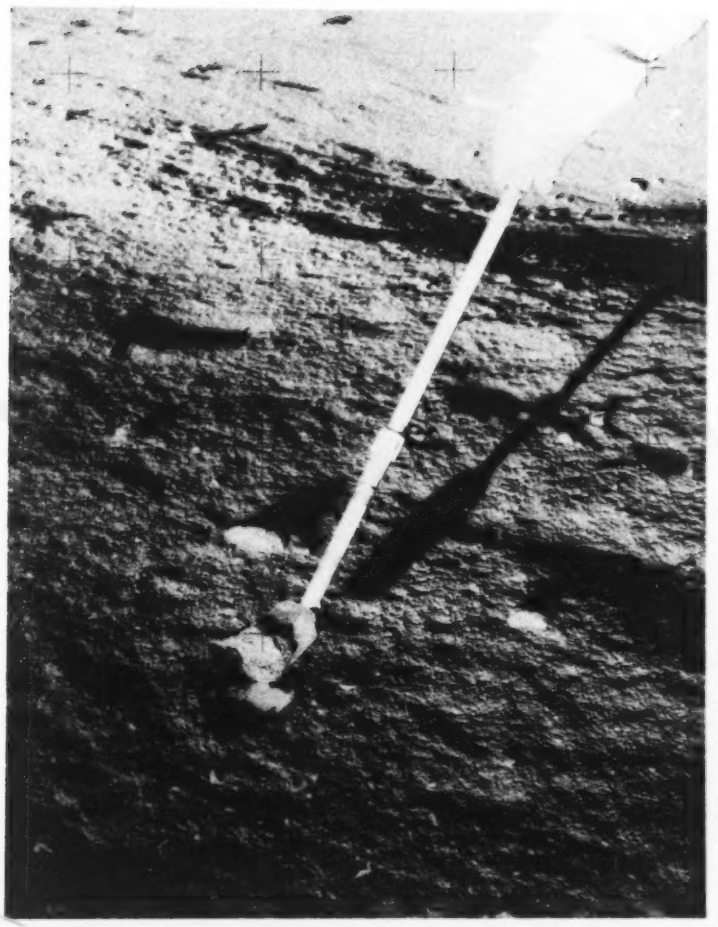


FIGURE 36.—Use of scoop in Apollo 12. Note the small rock in the scoop.

FIGURE 37.—Tongs shown in use on Apollo 12 to collect a small rock.

things that any hammer might be used on Earth. Because the astronaut cannot conveniently bend over and reach the lunar surface in his space suit, an extension handle is used with most tools. The scoop (figures 35 and 36) is used to collect lunar soil and occasionally small rocks. The tongs, sketched in figure 34 and shown in figure 37, an Apollo 12 photograph, are used to collect small rocks while standing erect.

The drive tubes (figure 38) are used to collect core material from the surface to depths of 1 to 4½ feet. The core remains in the tubes for return to Earth. Preservation of the relative depths of the core material is especially important. The drive tubes were originally suggested about 6 years ago by the late Dr. Hoover Mackin, a geologist. Shown in figure 39 is a drive tube that was driven into the Moon's surface on Apollo 14. The individual tubes are about 18 inches long. As many as three tubes can be used together for a total length of about 4½ feet.

After the surface samples are collected, they are placed in numbered sample bags made of Teflon (figure 40). These bags are about the size of the familiar kitchen storage bags. After a sample is bagged, the thin aluminum strip is folded to close the bag and prevent the samples from becoming mixed with others. The bags are finally placed in the sample return containers, sketched in figure 41, for return to Earth. The Apollo Lunar Sample Return Container (ALSRC) is about the size of a small suitcase. It is made of aluminum and holds 30 to 50 lbs. of samples.

A special container, termed Special Environmental Sample Container (SESC), is used to collect material on the surface of the Moon for specific purposes. (See figure 42.) This container has pressure seals to retain the extremely low pressures of the Moon. It is made of stainless steel. The sample to be collected on Apollo 15 and returned in this container will be collected in such a manner that it will have very little contamination with materials, either organic or inorganic, from Earth. The largest sources of biological contamination are the astronauts themselves; the suits leak many micro-organisms per minute and the lunar rocks collected on previous missions have all contained some organic material (a few parts per billion).

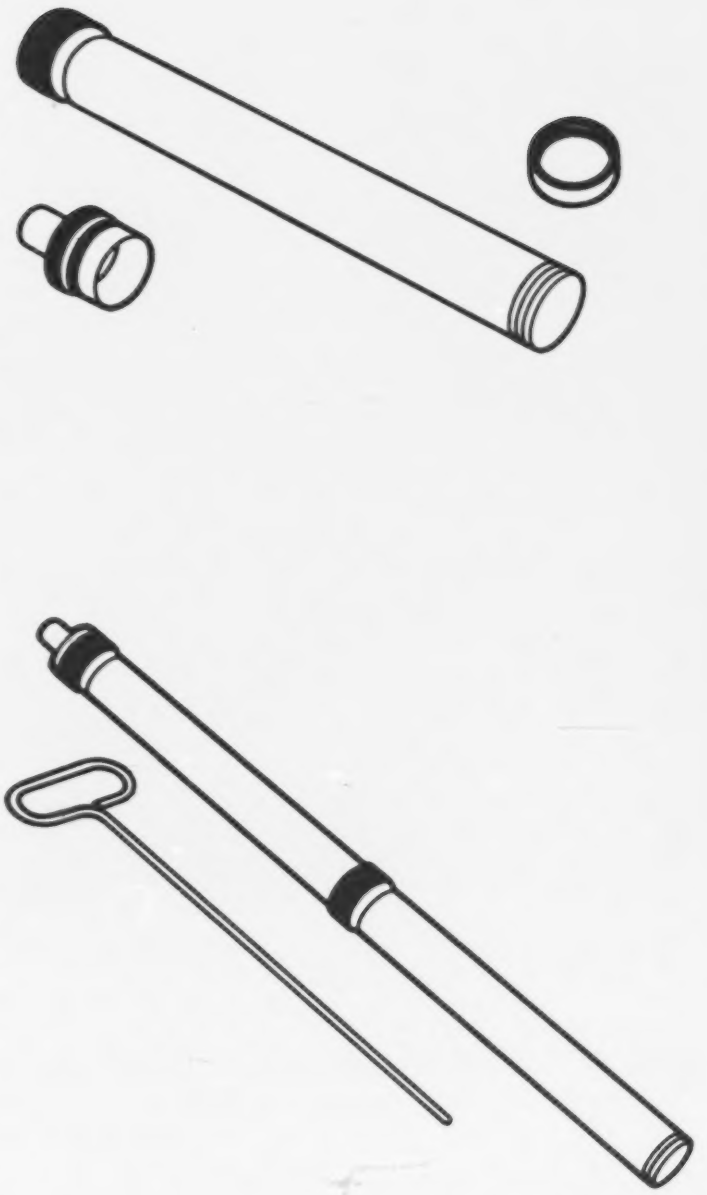


FIGURE 38.—Drive Tubes. These tubes, about 18 inches long, are pushed or driven into the lunar surface to collect samples as a function of depth. Two, three, or even four of them may be joined together to obtain a longer core. Their use in Apollo 14 may be seen in Figure 39.

FIGURE 39.—Drive tube in lunar surface at Apollo 14 site. Note in addition the footprints, rocks, and small craters.

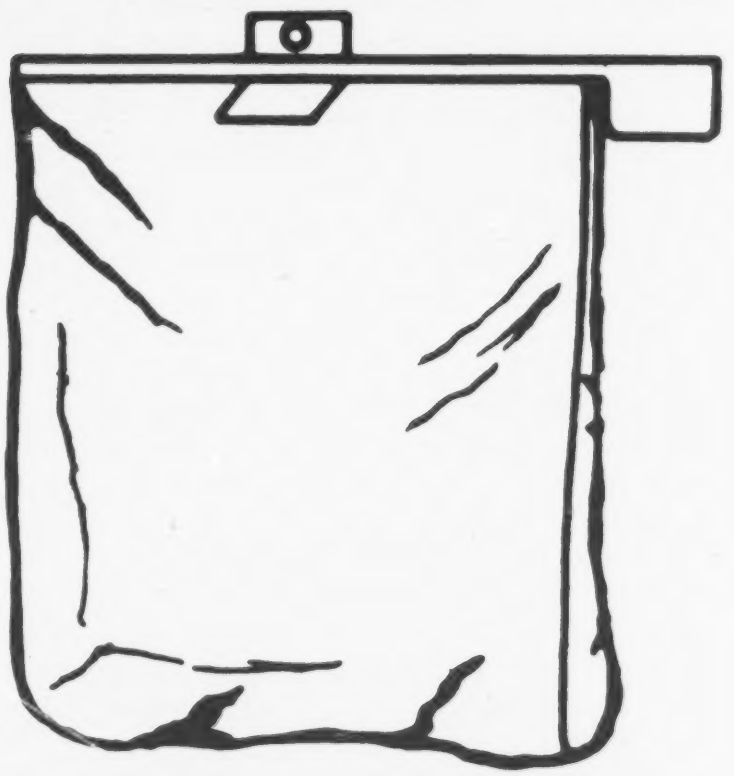


FIGURE 40.—Lunar sample bag. The bag resembles the familiar kitchen item "Baggies". It is made of Teflon. A strip of aluminum is used to close the bag.

Whether any of the organic material was present on the Moon before the astronauts' landing is uncertain; this question is currently being intensely investigated.

The Hasselblad cameras used by the astronauts (figure 43), were made especially for this use. The film is 70 mm wide, exactly twice as wide as the familiar 35 mm film. The color film is

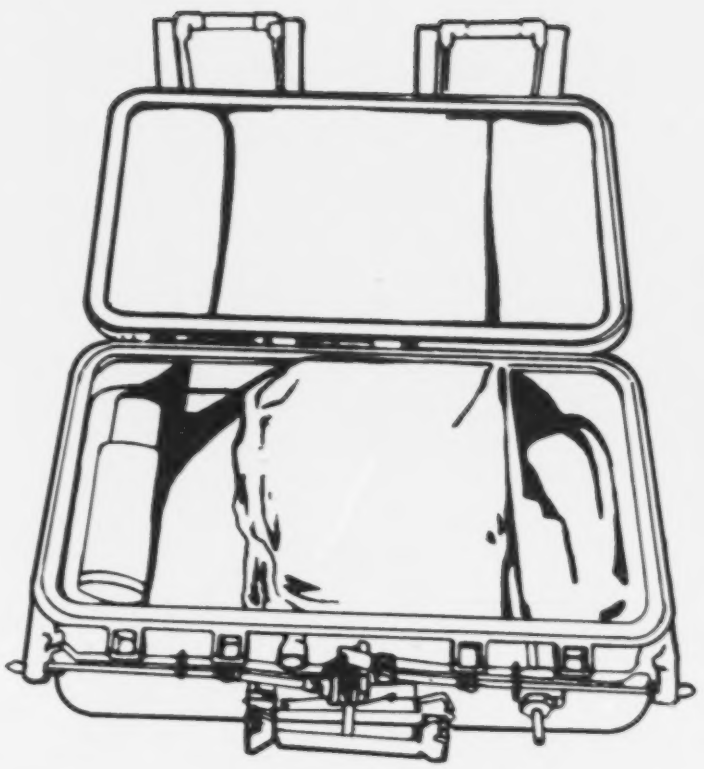


FIGURE 41.—Apollo Lunar Sample Return Container. Made of aluminum, this box is used to return lunar samples to Earth. It is about the size of a small suitcase but is many times stronger.

similar in characteristics to Ektachrome-EF daylight-type. The black and white film has characteristics like Plus X. The primary purpose of the cameras is that of documenting observations made by the astronauts. Especially important is the careful documentation of rocks that are collected for study back on Earth. Ideally, several photographs are taken of the rocks: (1) before collection with the Sun towards the astronaut's back, (2) before collection with the Sun to the side of the astronaut, (3) before collection a third photo to provide a stereo pair, and (4) after collection a single photo to permit us to see clearly which sample was collected. A device, termed gnomon and illustrated in figure 44, is included with these pictures to provide a scale with which to measure size and a calibration of the photometric properties of the Moon's surface. In addition to these photographs, a fifth one is desirable to show the general location of the sample with respect to recognizable features of the lunar surface. An example from Apollo 14 is seen in figure 45. The photos taken before collection and after collection show clearly which rock was removed.

At some stations, still more documentation is desirable. Panoramic views, also called pans, are obtained by shooting many photographs of the

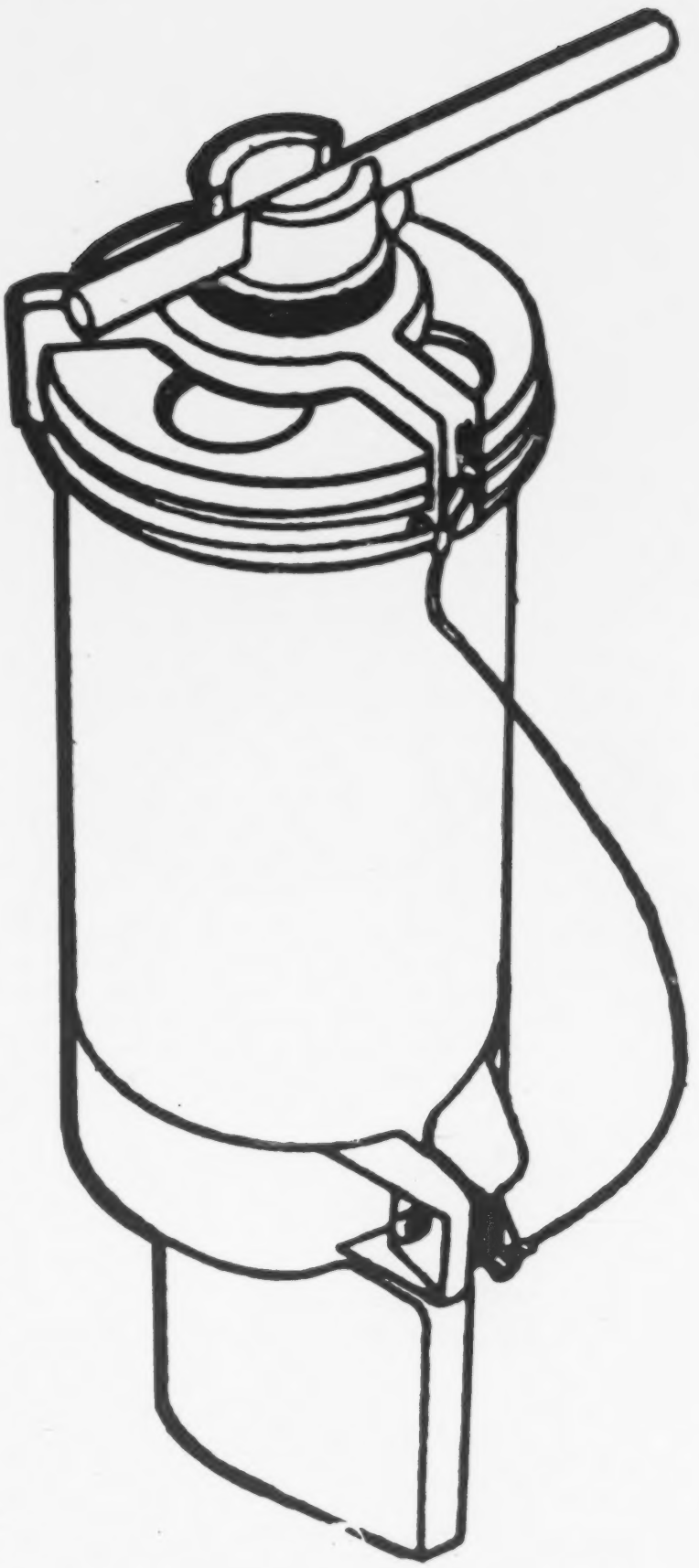
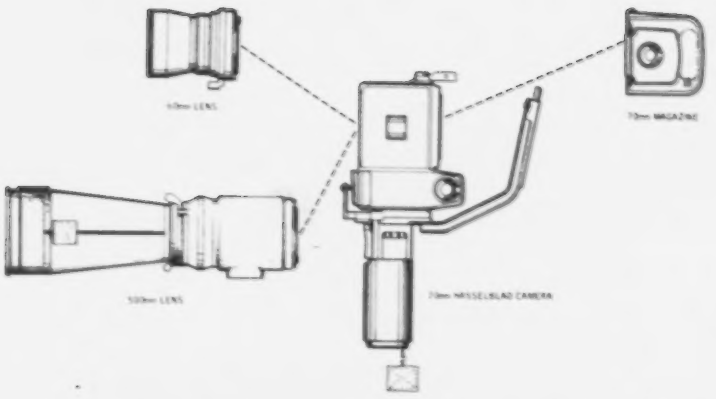


FIGURE 42.—Special Environmental Sample Container. This container has special vacuum seals to prevent gases and other materials from entering the container and being adsorbed on the surfaces during the journey to the Moon. They also prevent contamination of the samples by rocket exhaust gases and the Earth's atmosphere during the return journey.



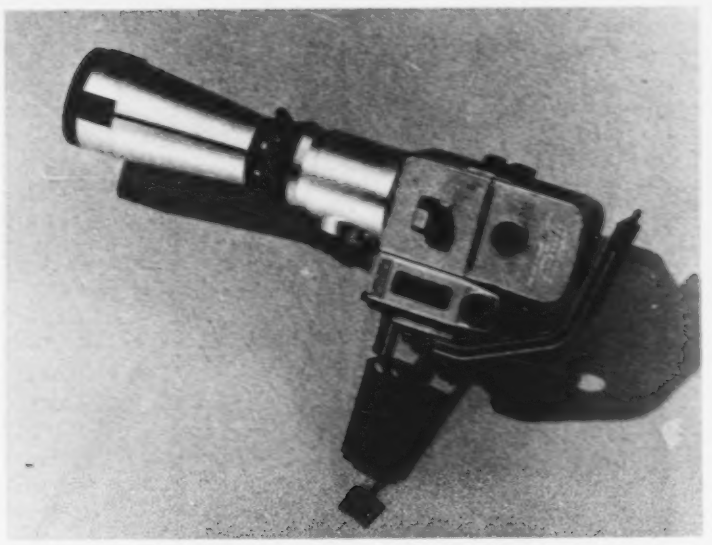


FIGURE 43.—Hasselblad camera. The film, which may be black and white or color, is 70 mm wide. Two separate lenses are used with this camera on the surface of the Moon. The 500 mm lens, a telephoto lens, shown attached to the camera in the photograph will be used to photograph the walls of Hadley Rille.

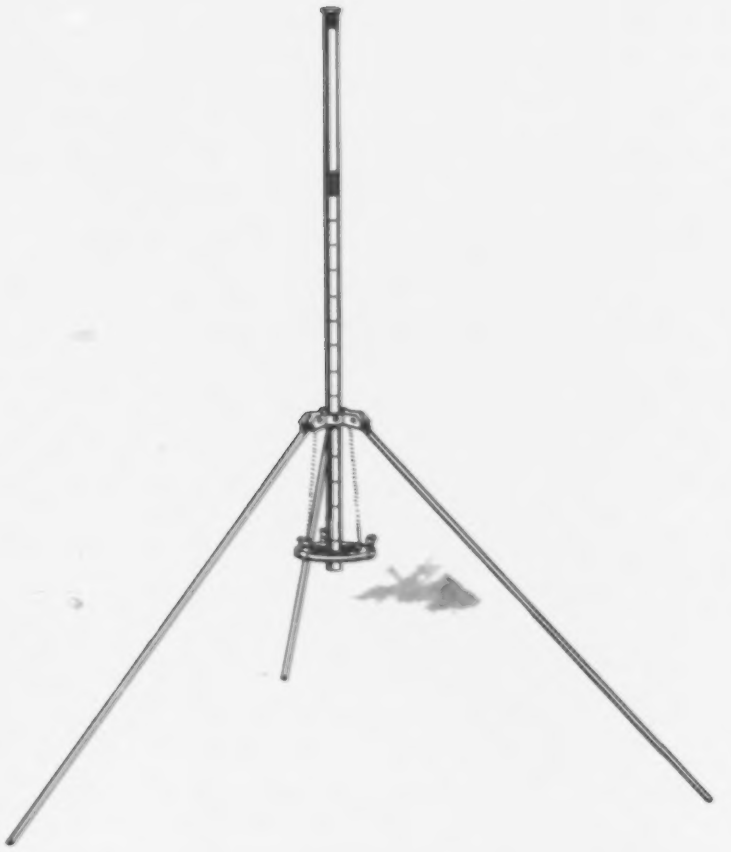


FIGURE 44.—Gnomon. This device is used to provide a physical scale and to calibrate the photometric properties of the samples on the Moon. It can also be seen in figure 45, an Apollo 14 photograph.

A B C

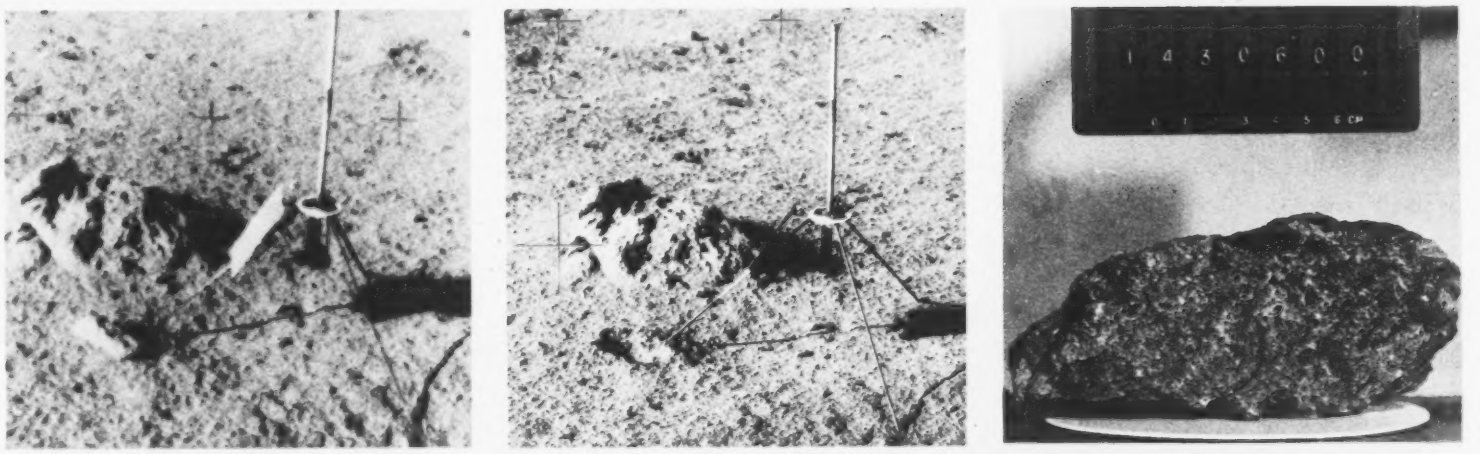


FIGURE 45.—Photographic documentation of lunar samples. These three Apollo 14 photographs indicate clearly the method used to identify the rocks that were collected. The shadows in A, together with knowledge of the time that the photo was taken, have been used to orient the specimen. A location photograph (not shown) allows us to determine the relative location of this sample with respect to others collected during the mission. Photo A was taken before the rock was collected. Photo B was taken after collection. Photo C was taken in the laboratory after the Apollo 14 mission had returned to Earth. The Field Geology Team, led by Dr. Gordon Swann, identified the rock in photos A and B as sample 14306 and deduced from photo A the orientation on the lunar surface.

horizon while turning a few degrees between snapping each successive photo. The photos have considerable overlap. After return to Earth, the overlap is eliminated and the photos pieced together to yield a composite view of the Moon's surface as seen from a particular spot. One example from Apollo 14 is shown in figure 46. Others may be seen in the July issue of National Geographic Magazine. In addition, the overlapped regions are used for stereoscopic viewing of the surface. Truly three-dimensional views are obtained in this way.

Marble-sized rocks from the Moon have proven to be especially valuable in lunar science. They are large enough to allow an extensive set of measurements to be made, yet small enough that many of them can be collected. Accordingly, we have designed and built a tool for Apollo 15 to collect many such samples. It is termed a rake, although the resemblance to the familiar garden tool is now slight. It is illustrated in figure 47.

The Apollo Lunar Surface Drill (ALSD), used to drill the two holes for the Heat Flow Experiment and illustrated in figure 22, is used also to drill a third hole from which the samples are saved. The drill bit is hollow and allows rock to pass into the hollow drill stem. These samples, referred to as core, are about 0.8 inch in diameter. Individual pieces of rock are likely to be button-shaped and ¼ inch thick. A few pieces may be larger. Most of the material will probably consist of lunar soil. These samples should not be confused with the samples obtained with the drive tubes

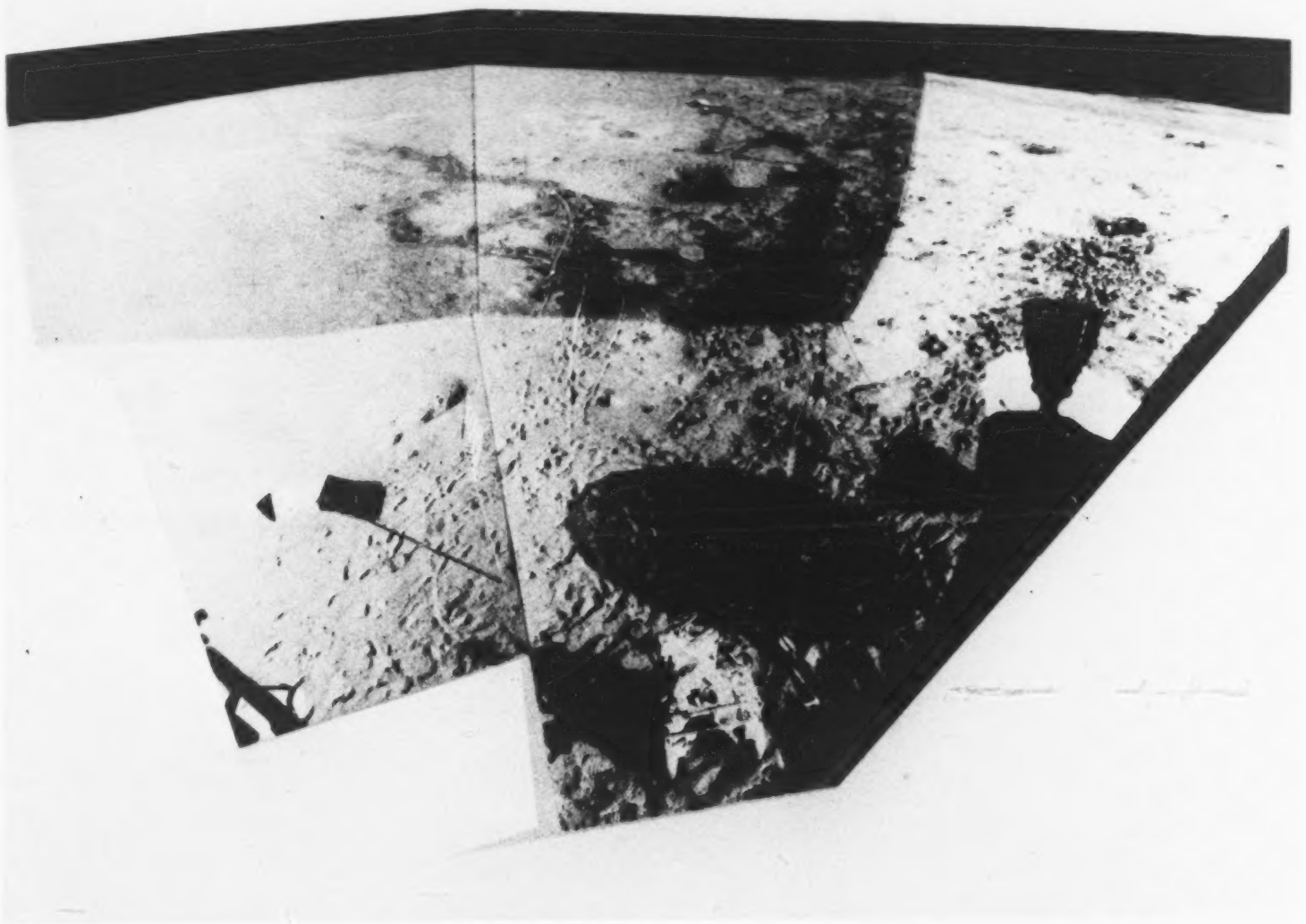


FIGURE 46.—Panoramic view obtained on Apollo 14. The method of piecing together several photos is clearly shown. Other panoramas may be seen in the July 1971 issue of National Geographic magazine. The tracks toward the upper left lead to ALSEP. The Mobile Equipment Transport is seen in the foreground. The elliptic shadow near the MET was cast by the S-band radio antenna used for communication with Earth. The TV camera is seen on the right-hand side of the pan. The inverted cone seen just below the TV camera is part of a small rocket engine used to turn the spacecraft in flight.

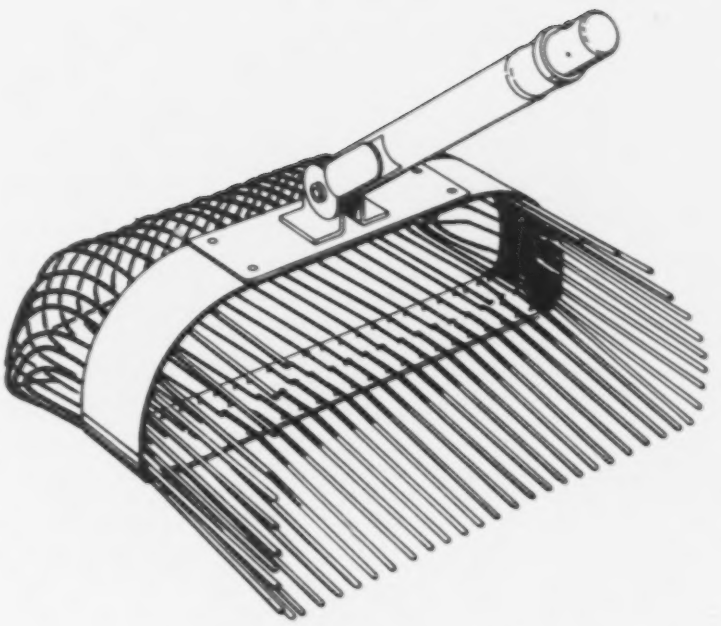


FIGURE 47.—Rake. This tool will be used on Apollo 15 to collect marble-size rocks.

which are also termed core. This equipment can drill and collect solid rock, if any is encountered, whereas the drive tubes can collect only material that is small enough to enter the tube.

Soil Mechanics Experiment

The mechanical properties of the lunar soil are important for both engineering and scientific reasons. Future design of spacecraft, surface vehicles, and shelters for use on the Moon will be based, in part at least, on the data collected in the soil mechanics experiment of this mission. To obtain data, many observations will be made during the performance of the other experiments. Such items as the quantity of dust ejected by the exhaust from the descending LM, the amount of dust thrown up by the wheels on the Rover and the depth to which the astronauts sink while walking, are all important factors in estimating the properties of the lunar soil. In addition to these qualitative observations, the astronauts will carry equipment with them with which to measure quantitatively the bearing strength of the soil, a recording penetrometer. It is illustrated in figure 48.

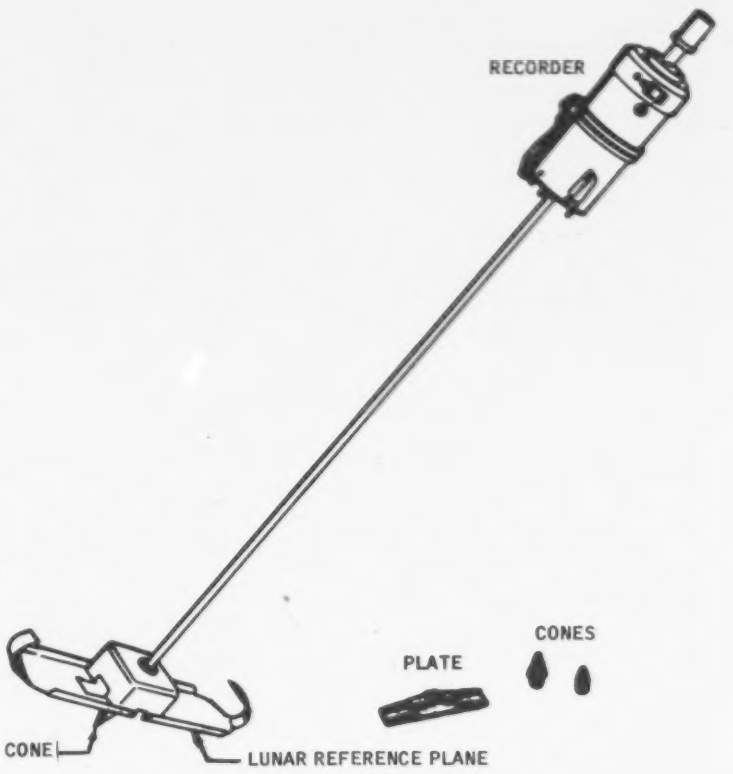


FIGURE 48.—Self-recording penetrometer.

The Crew

The prime crew consists of Dave Scott, Commander, Jim Irwin, LM pilot, and Al Worden, CM pilot. Scott and Neil Armstrong during the Gemini 8 mission performed the first successful docking of two vehicles in space. Scott was the CM pilot on Apollo 9 in 1969, the third manned flight in the Apollo series and backup commander for Apollo 12. Jim Irwin served as backup crew member for the Apollo 12 flight. Al Worden served as the backup Command Module pilot for Apollo 12.

The Apollo 15 backup crew consists of Dick Gordon, Commander, Vance Brand, CM pilot, and H. H. (Jack) Schmitt, LM pilot. The prime surface crew is shown in figures 49, 50 and 51. The backup crew is shown in figures 52 and 53.

This crew, like previous ones, has undergone intensive training during the past few months and somewhat more casual training during the last few years. In addition to the many exercises needed to learn to fly proficiently their spacecraft, the astronauts have learned much about science, and in particular, about lunar science. After all, they will each spend many hours on the Moon or in orbit around the Moon performing scientific research. The surface astronauts have had tutorial sessions with many of the nation's best scientists. They are able to set up experiments, such as those of ALSEP, but more importantly, they understand the scientific purposes behind the various experiments.

Most of the time on the lunar surface during Apollo 15 will be spent observing geologic features and collecting samples. Obviously anyone can pick up rocks with which to fill boxes and bags. Only a person highly trained in the geosciences, however, can properly select those few rocks from many that are likely to yield the greatest amount of scientific return when examined in minute detail in the laboratory back on Earth. The Apollo 15 crew has spent many hours in the field studying rocks under the guidance of geologists from the U.S. Geological Survey, several universities, and NASA's Manned Spacecraft Center. The prime crew has been especially fortunate in having the constant geologic tutelage of Astronaut Jack Schmitt, a geologist himself.

FIGURE 49.—Apollo 15 astronauts Jim Irwin and Dave Scott study geology on a field trip near Taos, New Mexico, in March 1971. In the left background, shown in profile with Texas-style hat, is Professor Lee Silver, a field geologist from the California Institute of Technology who has contributed significantly toward geological training of the crew.

FIGURE 50.—Apollo 15 astronauts Jim Irwin (left) and Dave Scott during the field trip to study geology near Taos, New Mexico. During such training exercises, the astronauts typically carry backpacks that simulate the PLSS. Note the Hasselblad cameras, the scoop, and the gnomon.

FIGURE 52.—Apollo 15 backup surface crew, Dick Gordon (left) and Jack Schmitt. They are using the self-recording penetrometer to measure soil properties near Taos, New Mexico.

FIGURE 51.—CM Pilot Al Worden. A major part of the crew's training in science is the study of geology. Worden is recording his observations of the rocks at this training site.

FIGURE 53.—Astronaut Vance Brand collects rocks on a training trip to Iceland. During the training exercises, the astronauts record their observations on the rocks and geological features.

Bibliography

This bibliography is not intended to be extensive. It is a guide to simply-written, and mostly inexpensive, books that I believe useful for additional reading.

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American Association for the Advancement of Science, Washington, D.C., *Apollo 11 Lunar Science Conference*, McCall Printing Company, 1970. Historic milepost in lunar science. Contains the first public release of information obtained on the Apollo 11 samples by several hundred scientists. Written for fellow scientists. Obtain from AAAS, 1515 Massachusetts Avenue, N.W., Washington, D.C. 20005, Hardback $14.00, Paperback $3.00.

Baldwin, Ralph B., *The Measure of the Moon*, The University of Chicago Press, 1963. Exhaustive study of the Moon. Important summary of knowledge of the Moon that existed before the lunar flights began. Although in places, the reading may be a little difficult, it is generally accessible to the layman, $13.50.

Cortright, Edgar M., ed., *Exploring Space with a Camera*, NASA SP–168, NASA, Washington. D.C. Inexpensive. Contains many beautiful photographs obtained from space. Well worth the small investment for the layman with even mild interests in space. Government Printing Office, Washington, D.C. $4.25.

Hess, Wilmot, Robert Kovach, Paul W. Gast and Gene Simmons, *The Exploration of the Moon*, Scientific American, Vol. 221, No. 4, October 1969, pp. 54–72. General statement of plans for lunar exploration. Written before first lunar landing. Suitable for layman. The authors were all instrumental in planning the lunar surface scientific operations of the Apollo program. Reprint available from W. H. Freeman and Company, 600 Market St., San Francisco, Calif. 94104, 25¢ postage paid.

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NASA, *Earth Photographs from Gemini VI through XII*, NASA SP–171, NASA, Washington, D.C., 1968. Contains many beautiful photographs of the Earth from space. In color. U.S. Government Printing Office, Washington, D.C. $8.00.

NASA, *Surveyor Program Results*, NASA SP–184, NASA, Washington, D.C., 1969. Final report of the results obtained in the Surveyor Program. Surveyor was the first soft-landed spacecraft on the Moon and provided many important data. Because only one of the Surveyor sites has been revisited, the data given in this book are very important to our current understanding of the Moon. Part is easily readable by the layman; some is more difficult. U.S. Government Printing Office, Washington, D.C., $4.75.

Wood, John A., *Meteorites and the Origin of Planets*, McGraw-Hill Book Company, 1968. Inexpensive. Suitable for layman. Good introduction to meteorites.

Acronyms

ALSEP	Apollo lunar surface experiments package
ALSRC	Apollo lunar sample return container
CCIG	cold cathode ion gauge
CM	command module
CSM	command and service module
DPS	descent propulsion system
e.s.t.	eastern standard time
EVA	extravehicular activity
HFE	heat flow experiment
g.e.t.	ground elapsed time
G.m.t.	Greenwich mean time
IR	infrared
JPL	Jet Propulsion Laboratory
LDD	lunar dust detector
LGE	lunar geology experiment
LM	lunar module
LRL	Lunar Receiving Laboratory, NASA Manned Spacecraft Center
LRRR	laser ranging retro-reflector
LRV	lunar roving vehicle
LSM	lunar surface magnetometer
MIT	Massachusetts Institute of Technology
MSC	Manned Spacecraft Center
NASA	National Aeronautics and Space Administration
PLSS	portable life support system
PSE	passive seismic experiment
RCS	reaction control system
RTG	radioisotope thermoelectric generator
SESC	surface environment sample container
SIDE	suprathermal ion detector experiment
S-IVB	Saturn IVB (rocket stage)
SME	soil mechanics experiment
SWC	solar wind composition experiment
SWS	solar wind spectrometer experiment
TV	television
USGS	U.S. Geological Survey

Glossary

ALBEDO
al-bee-doh
Relative brightness. It is the ratio of the amount of electromagnetic radiation reflected by a body to the amount of incident radiation.

ANGSTROM UNIT
ang-strom
A unit of length equal to 10^{-10} meters or 10^{-4} microns. It is approximately four-billionths of an inch. In solids, such as salt, iron, aluminum, the distance between atoms is usually a few Angstroms.

APERTURE
a-per-ture
A small opening such as a camera shutter through which light rays pass to expose film when the shutter is open.

ATTENTUATION
a-ten-u-eh-shun
Decrease in intensity usually of such wave phenomena as light or sound.

BASALT
ba-salt
A type of dark gray rock formed by solidification of molten material. The rocks of Hawaii are basalts.

BISTATIC RADAR
bi-sta-tic ray-dar
The electrical properties of the Moon's surface can be measured by studying the characteristics of radio waves reflected from the Moon. If the radio transmitter and receiver are located at the same place, the term monostatic radar is used. If they are located at different places, then bistatic is used. In the study of the Moon with bistatic radar, the transmitter is aboard the CSM and the receiver is on the Earth.

BRECCIA
brech-ya
A coarse-grained rock composed of angular fragments of pre-existing rocks.

CASSETTE
kuh-set
Photographic film container.

CISLUNAR
sis-lune-ar
Pertaining to the space between the Earth and Moon or the Moon's orbit.

COLORIMETRIC
Pertaining to the measurement of the intensities of different colors as of lunar surface materials.

COSMIC RAYS
kos-mik
Streams of very high energy nuclear particles, commonly protons, that bombard the Earth and Moon from all directions.

COSMOLOGY
kos-mol-uh-gee
Study of the character and origin of the universe.

CRATER
cray-ter
A naturally occurring hole. On Earth, a very few craters are formed by meteorites striking the Earth; most are caused by volcanoes. On the Moon, most craters were caused by meteorites. Some lunar craters were apparently formed by volcanic processes. In the formation of lunar craters, large blocks of rock (perhaps as large as several hundred meters across) are thrown great distances from the crater. These large blocks in turn form craters also—such craters are termed secondary craters.

CROSS-SUN
A direction approximately 90 degrees to the direction to the Sun and related to lunar surface photography.

CROSSTRACK
Perpendicular to the instantaneous direction of a spacecraft's ground track.

CRYSTALLINE ROCKS
Rocks consisting wholly or chiefly of mineral crystals. Such rocks on the Moon usually formed by cooling from a liquid melt.

DIELECTRIC
dye-ee-lek-trik
A material that is an electrical insulator. Most rocks are dielectrics.

DIURNAL
dye-er-nal
Recurring daily. Diurnal processes on Earth repeat themselves every 24 hours but on the Moon repeat every 28 earth days. The length of a lunar day is 28 earth days.

DOPPLER TRACKING
dopp-lur
A system for measuring the trajectory of spacecraft from Earth using continuous radio waves and the Doppler effect. An example of the Doppler effect is the change in pitch of a train's whistle and a car's horn on passing an observer. Because of this effect, the frequency of the radio waves received on Earth is changed slightly by the velocity of the spacecraft in exactly the same way that the pitch of a train's whistle is changed by the velocity of the train.

DOWN-SUN — In the direction of the solar vector and related to lunar surface photography.

EARTHSHINE — Illumination of the Moon's surface by sunlight reflected from the Earth. The intensity is many times smaller than that of the direct sunlight.

ECLIPTIC PLANE
ee-klip-tik — The plane defined by the Earth's orbit about the Sun.

EFFLUENT
eff-flu-ent — Any liquid or gas discharged from a spacecraft such as waste water, urine, fuel cell purge products, etc.; also any material discharged from volcanoes.

EGRESS
ee-gress — A verb meaning to exit or to leave. The popularization of this word has been attributed to the great showman, P. T. Barnum, who reportedly discovered that a sign marked exit had almost no effect on the large crowds that accumulated in his exhibit area but a sign marked "to egress" led the crowds outdoors. In space terminology it means simply to leave the spacecraft.

EJECTA
ee-jek-tuh — Lunar material thrown out (as resulting from meteoroid impact or volcanic action).

ELECTRON
ee-lek-tron — A small fundamental particle with a unit of negative electrical charge, a very small mass, and a very small diameter. Every atom contains one or more electrons. The *proton* is the corresponding elementary particle with a unit of positive charge and a mass of 1837 times as great as the mass of the electron.

FIELD — A region in which each point has a definite value such as a magnetic field.

FIELD OF VIEW — The region "seen" by the camera lens and recorded on the film. The same phrase is applied to such other equipment as radar and radio antennas.

FILLET
fill-it — Debris (soil) piled against a rock; several scientists have suggested that the volume of the fillet may be directly proportional to the time the rock has been in its present position and to the rock size.

FLUORESCENCE
flur-es-ence — Emission of radiation at one wavelength in response to the absorption of energy at a different wavelength. Some lunar materials fluoresce. Most do not. The process is identical to that of the familiar fluorescent lamps.

FLUX — The rate of flow per unit area of some quantity such as the flux of cosmic rays or the flux of particles in the solar wind.

FRONT — The more or less linear outer slope of a mountain range that rises above a plain or plateau. In the U.S., the Colorado Front Range is a good example.

GALACTIC
ga-lak-tik — Pertaining to a galaxy in the universe such as the Milky Way.

GAMMA — A measure of magnetic field strength; the Earth's magnetic field is about 50,000 gamma. The Moon's magnetic field is only a few gamma.

GAMMA-RAY — One of the rays emitted by radioactive substances. Gamma rays are highly penetrating and can traverse several centimeters of lead.

GEGENSCHEIN
geg-en-schine — A faint light covering a 20-degree field-of-view projected on the celestial sphere about the Sun-Earth vector (as viewed from the dark side of the Earth).

GEOCHEMICAL GROUP — A group of three experiments especially designed to study the chemical composition of the lunar surface remotely from lunar orbit.

GEODESY
gee-odd-eh-see — Originally, the science of the *exact* size and shape of the Earth; recently broadened in meaning to include the Moon and other planets.

GEOPHYSICS
gee-oh-phys-ics — Physics of planetary bodies, such as the Earth and Moon, and the surrounding environment; the many branches include gravity, magnetism, heat flow, seismology, space physics, geodesy, meteorology, and sometimes geology.

GNOMON
know-mon — A rod mounted on a tripod in such a way that it is free to swing in any direction and indicates the local vertical; it gives sun position and serves as a size scale. Color and reflectance scales are provided on the rod and a colorimetric reference is mounted on one leg.

GRADIENT
gray-dee-unt — The rate of change of something with distance. Mathematically, it is the space rate of change of a function. For example, the slope of a mountain is the gradient of the elevation.

INGRESS
in-gress — A verb meaning to enter. It is used in connection with entering the LM. See also "egress."

IN SITU
in-site-u — Literally, "in place", "in its original position". For example, taking photographs of a lunar surface rock sample "in situ" (as it lays on the surface).

LIMB — The outer edge of the apparent disk of a celestial body, as the Moon or Earth, or a portion of the edge.

MANTLE — An intermediate layer of the Moon between the outer layer and the central core.

MARE
maar — A large dark flat area on the lunar surface (Lunar Sea). May be seen with the unaided eye.

MARIA *maa-ya*	Plural of mare.
MASCONS *mass-conz*	Large mass concentrations beneath the surface of the Moon. They were discovered only three years ago by changes induced by them in the precise orbits of spacecraft about the Moon.
MASS SPECTROMETER *mass spek-trom-a-tur*	An instrument which distinguishes chemical species in terms of their different isotopic masses.
METEORRITE *me-te-oh-rite*	A solid body that has arrived on the Earth or Moon from outer space. It can range in size from microscopic to many tons. Its composition ranges from that of silicate rocks to metallic ion-nickel. For a thorough discussion see *Meteorites* by Brian Mason, John Wiley and Sons, 1962.
MICROSCOPIC	Of such a size as to be invisible to the unaided eye but readily visible through a microscope.
MINERALOGY	The science of minerals; deals with the study of their atomic structure and their general physical and chemical properties.
MONOPOLE *mon-oh-pole*	All known magnets have two poles, one south pole and one north pole. The existence of a single such pole, termed a monopole, has not yet been established but is believed by many physicists to exist on the basis of theoretical studies. Lunar samples have been carefully searched on Earth for the presence of monopoles.
MORPHOLOGY *mor-fol-uh-ge*	The external shape of rocks in relation to the development of erosional forms or topographic features.
NADIR	That point on the Earth (or Moon) vertically below the observer.
OCCULTATION *ah-cull-tay-shun*	The disappearance of a body behind another body of larger apparent size. For example the occultation of the Sun by the Moon as viewed by an earth observer to create a solar eclipse.
OZONE *oh-zone*	Triatomic oxygen (O_3); found in significant quantities in the Earth's atmosphere.
PANORAMA *pan-uh-ram-a*	A series of photographs taken from a point to cover 360 degrees around that point.
PENUMBRAL *pe-num-bral*	Referring to the part of a shadow in which the light (or other rays such as the solar wind) is only partially masked, in contrast to the umbra in which light is completely masked, by the intervening object.
PETROGRAPHY *pe-trog-rah-fy*	Systematic description of rocks based on observations in the field, on hand specimens, and on microscopic examination.
PLASMA *plazz-muh*	An electrically conductive gas comprised of neutral particles, ionized particles and free electrons but which, when taken as a whole, is electrically neutral.
PRIMORDIAL *pry-mor-dee-uhl*	Pertaining to the earliest, or original, lunar rocks that were created during the time between the initial and final formation stages of the Moon.
PROTON *prow-ton*	The positively charged constituent of atomic nuclei. For example, the entire nucleus of a hydrogen atom having a mass of 1.67252×10^{-27} kilograms.
RAY	Bright material that extends radially from many craters on the Moon; believed to have been formed at the same time as the associated craters were formed by impacting objects from space; usually, but not always, arcs of great circles. They may be several hundred kilometers long.
REGOLITH *reg-oh-lith*	The unconsolidated residual material that resides on the solid surface of the Moon (or Earth).
RETROGRADE	Lunar orbital motion opposite the direction of lunar rotation.
RILLE/RILL	A long, narrow valley on the Moon's surface.
RIM	Elevated region around craters and rilles.
SAMPLE	Small quantities of lunar soil or rocks that are sufficiently small to return them to Earth. On each mission several different kinds of samples are collected. Contingency sample consists of 1 to 2 pounds of rocks and soil collected very early in the surface operations so that at least some material will have been returned to Earth in the event that the surface activities are halted abruptly and the mission aborted. Documented sample is one that is collected with a full set of photographs to allow positive identification of the sample when returned to Earth with the sample in situ together with a complete verbal description by the astronaut. Comprehensive sample is a documented sample collected over an area of a few yards square.
S-BAND	A range of frequencies used in radar and communications that extends from 1.55 to 5.2 kilomegahertz.
SCARP	A line of cliffs produced by faulting or erosion.

SEISMIC *sizé-mik*	Related to mechanical vibration within the Earth or Moon resulting from, for example, impact of meteoroids on the surface.
SOLAR WIND	Streams of particles (mostly hydrogen and helium) emanating from and flowing approximately radially outward from the Sun.
SPATIAL	Pertaining to the location of points in three-dimensional space; contrasted with temporal (pertaining to time) locations.
SPECTROMETER	An instrument which separates radiation into energy bands (or, in a mass spectrometer, particles into mass groups) and indicates the relative intensities in each band or group.
SPUR	A ridge of lesser elevation that extends laterally from a mountain or mountain range.
STELLAR	Of or pertaining to stars.
STEREO	A type of photography in which photographs taken of the same area from different angles are combined to produce visible features in three-dimensional relief.
SUPPLEMENTARY SAMPLE STOP	A stop added to a traverse after the stations are numbered. Mission planning continues through launch and the supplementary sample stops are inserted between normal traverse stations.
SUPRATHERMAL *soup-rah-therm-al*	Having energies greater than thermal energy.
SUBSATELLITE	A small unmanned satellite, deployed from the spacecraft while it is in orbit, designed to obtain various types of solar wind, lunar magnetic, and S-band tracking data over an extended period of time.
TALUS *tail-us*	Rock debris accumulated at the base of a cliff by erosion of material from higher elevation.
TEMPORAL	Referring to the passage or measurement of time.
TERMINATOR *term-ugh-nay-tor*	The line separating the illuminated and the darkened areas of a body such as the Earth or Moon which is not self-luminous.
TERRA *terr-ugh*	Those portions of the lunar surface other than the maria; the lighter areas of the Moon. They are visible to the unaided eye.
TIDAL	Referring to the very small movement of the surface of the Moon or the Earth due to the gravitational attraction of other planetary bodies. Similar to the oceanic tides, the solid parts of the Earth's crust rise and fall twice daily about three feet. Lunar tides are somewhat larger. The tides of solid bodies are not felt by people but are easily observed with instruments.
TIMELINE	A detailed schedule of astronaut or mission activities indicating the activity and time at which it occurs within the mission.
TOPOGRAPHIC *Top-oh-gra-fick*	Pertaining to the accurate graphical description, usually on maps or charts, of the physical features of an area on the Earth or Moon.
TRANSEARTH	During transit from the Moon to the Earth.
TRANSIENT *tran-shé-unt*	A short-lived, random event; often occurring in a system when first turned-on and before reaching operating equilibrium. For example, the initial current surge that occurs when an electrical system is energized.
TRANSLUNAR	During transit from the Earth to the Moon.
TRANSPONDER *trans-pón-der*	A combined receiver and transmitter whose function is to transmit signals automatically when triggered by a suitable radio signal.
UMBRA *um-bruh*	The dark central portion of the shadow of a large body such as the Earth or Moon; compare penumbra.
UP-SUN	Into the direction of the Sun and related to lunar surface photography.
URANIUM *your-rain-nee-um*	One of the heavy metallic elements that are radioactive.
VECTOR	A quantity that requires both magnitude and direction for its specification, as velocity, magnetic force field and gravitational acceleration vectors.
WAVELENGTH	The distance between peaks (or minima) of waves such as ocean waves or electromagnetic waves.
X-RAY	Electromagnetic radiation of non-nuclear origin within the wavelength interval of 0.1 to 100 Angstroms (between gamma-ray and ultra-violet radiation). X-rays are used in medicine to examine teeth, lungs, bones, and other parts of the human body; they also occur naturally.
ZODIACAL LIGHT *zow-dyé-uh-cal*	A faint glow extending around the entire zodiac but showing most prominently in the neighborhood of the Sun. (It may be seen in the west after twilight and in the east before dawn as a diffuse glow. The glow may be sunlight reflected from a great number of particles of meteoritic size in or near the ecliptic in the planetoid belt).

Tables

TABLE 1.—*Timeline of Apollo 15 Mission Events**

Event	Time from liftoff (hr/min)	CDT/date
Launch		8:34 am July 26
Earth Orbit Insertion	00:12	8:46 am
Trans Lunar Injection	2:50	11:24 am
Lunar Orbit Insertion	78:31	3:05 pm July 29
Descent Orbit Insertion	82:40	7:14 pm
Spacecraft Separation	100:14	12:48 pm July 30
Lunar Landing	104:42	5:15 pm
Stand Up EVA	106:10	6:43 pm
EVA 1	119:50	8:24 am July 31
EVA 2	141:10	5:44 am August 1
EVA 3	161:50	2:24 am August 2
Lunar Liftoff	171:38	12:12 pm
Spacecraft Docking	173:30	2:04 pm
Trans Earth Injection	223:44	4:18 pm August 4
Trans Earth EVA	242:00	10:34 am August 5
Pacific Ocean Splashdown. (26° N. Lat./ 158° W Long.)	295:12	3:46 pm August 7

*These times are exact for launch on 26 July 71. They change somewhat for other launch dates.

TABLE 2.—*LRV Exploration Traverse*

[The entries in this table are brief. They are explained in the text and in the glossary. The table should be considered a general guide only; not every item is mandatory at each stop. The times are especially likely to change during the mission. The reader may wish to mark the actual times for himself on the table]

Station/activity	Elapsed time at start (hr:min)	Segment time (hr:min)	Geological features	Observations and activities
			EVA I	
LM		1:25	Smooth mare	Observe LM, prepare for departure from moon, contingency sample, deploy LRV
Travel	1:25	0:17	Across typical smooth mare material toward rim of Hadley Rille	Observe and describe traverse over smooth mare material Describe surface features and distribution of large boulders Note any difference between mare and rille rim material
Check Point	1:42	0:02		
Travel	1:44	0:07	Around Elbow Crater	Observe low ridge around Elbow Crater Observe any differences between rille rim material and mare material

TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Elapsed time at start (hr:min)	Segment time (hr:min)	Geological features	Observations and activities
			EVA I—Continued	
				Observe distribution of ejecta around Elbow Crater
1	1:51	0:15	Southern part of Elbow Crater ejecta blanket	Radial sampling of rocks at Elbow Crater Panoramic photography
Travel	2:06	0:08	To Apennine Front slope north of St. George Crater	Look for changes in rocks or ground that indicate the base of the mountain Compare the material of the Front with mare and rille rim material Observe character and distribution of St. George ejecta blanket
2	2:14	0:45	Near base of Apennine Front north of St. George Crater	Radial sampling of rocks at St. George Crater Comprehensive sample in area at Front Double drive core tube 500mm lens camera photography of blocks on rim of St. George and of rille Stereo pan from high point Fill SESC at Apennine Front Penetrometer
Travel	2:59	0:09	Across base of Apennine Front to edge of possible debris flow	Observe Apennine material and its relation to mare surface
Area Stop 3	3:08	0:14	At base of Apennine Front adjacent to possible debris flow	Examine flow and compare with mare and Front Documented samples of Apennine Front and flow material Observe and describe vertical and lateral changes in Apennine Front; compare with previous stop Panoramic photography Observe characteristics of EVA II route
Travel	3:22	0:28	From base of Apennine Front across mare to LM	Observe characteristics and extent of possible debris flow Observe area to be traversed on EVA II Compare mare material with Apennine Front and rille rim Observe possible ray material
LM	3:50	3:10	Smooth mare	ALSEP deployment—see Table 3 for details Store samples and records Ingress LM
			EVA II	
LM		0:49	Smooth mare	Egress LM, prepare for traverse
Travel	0:49	0:11	South along smooth mare SW of secondary crater cluster to base of Apennine Front	Observe smooth mare characteristics Observe secondary crater cluster characteristics Traverse along Apennine Front; determine position of base of Front and search for optimum sampling areas for stops on return leg of traverse Photography as appropriate
Check Point	1:00	0:02		
Travel	1:02	0:15	East along Apennine Front	Same as above
4	1:17	0:20	Secondary crater cluster south of 400m crater	Soil/rake sample Documented samples Panoramic photography 500mm photography of Apennine Front Exploratory trench Possibly drive core tube through secondary ejecta Observe crater interior and ejecta Sample both typical and exotic rock types Compare secondary crater material with other geologic units at the site

TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Elapsed time at start (hr:min)	Segment time (hr:min)	Geological features	Observations and activities
			EVA II—Continued	
Travel	1:37	0:10	South along smooth mare SW at secondary crater cluster to base of Apennine Front	Observe smooth mare characteristics Observe secondary crater cluster characteristics and crater forms Photography as appropriate
Check Point	1:47	0:04		
Travel	1:51	0:10	East along Apennine Front	Traverse along Apennine Front; determine position of base of Front and search for optimum sampling areas for stops on return leg of traverse Photography as appropriate Observe possible debris flows, downslope movement; look for source
Check Point	2:01	0:04		
Travel	2:05	0:05	East along Apennine Front	Same as above
Check Point	2:10	0:04		
Travel	2:14	0:12	Along Apennine Front to area stop 5	Same as above
Area Stop 5	2:26	0:51	At base of Apennine Front near rim of Front Crater	Documented samples from upslope side of Front Crater in Apennine Front Documented samples from northern rim of Front Crater; particularly at sharp 80-m crater on rim Stereo pan Exploratory trench upslope of Front Crater 500mm photography of any interesting targets Stereo pairs upslope of any interesting targets
Travel	3:19	0:15	Along base of Apennine Front	Observe lateral variations in material and surface textures Search for blocky areas along Apennine Front which are suitable for sampling (craters, etc.) Photography as appropriate
6	3:32	0:44	Along base of Apennine Front on slope in intercrater areas or on crater rims; chosen at crew's discretion, based on previous observations	Include the following activities which should be modified according to the local geology: Description of Apennine Front in sampling area Comparison of Apennine Front and of the material there with other surface units Documented samples of Apennine Front material Panoramic photography Exploratory trench Possible drive core tube 500mm photography Stereo pairs of interesting features upslope
Travel	4:16	0:08	Along base of Apennine Front	Observe lateral variations in material and surface textures Search for blocky areas along Apennine Front which are suitable for sampling (craters, etc.) Photography as appropriate
7	4:24	0:44	Along base of Apennine Front on slope in intercrater areas or on crater rims; chosen at crew's discretion, based on previous observations	Observe lateral variations in material and surface textures Search for blocky areas along Apennine Front which are suitable for sampling (craters, etc.) Photography as appropriate At the last Apennine Front stop, based on previous observations along Front, crew uses discretion to complete sampling

TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Elapsed time at start (hr:min)	Segment time (hr:min)	Geological features	Observations and activities
			EVA II—Continued	
Travel	5:08	0:22	From base of Apennine Front along southwestern edge of secondary crater cluster	Observe secondary crater deposits and relation to other terrain Observe eastern edge of possible debris flow from Apennine Front Photography as appropriate
8	5:30	0:37	Mare material near crater	Comprehensive sample area Double core tube Documented sampling of large mare crater Possible fillet/rock sample Possible large and small equidimensional rock samples Panoramic photography Trench Possible buried rock sample Fill SESC Penetrometer
Travel	6:07	0:13	Across smooth mare	Compare mare material with other lunar material Observe possible ray material
LM	6:20	0:40	Smooth mare	Store samples and records Ingress LM
			EVA III	
LM		0:42	Smooth mare	Egress LM, prepare for traverse
Travel	0:42	0:07	Across smooth mare between LM and rim of Hadley Rille	Compare smooth mare material with rille rim material
Supplementary Sample Stop	0:49	0:05	Smooth mare between LM and rim of Hadley Rille	Soil/rock sample Panoramic photography
Travel	0:54	0:12	Across smooth mare to rille rim turning NW at rille rim to the Terrace	Compare smooth mare material to rille rim material
9	1:06	0:50	At rim of Hadley Rille at southern end of the Terrace	Observe and describe rille and far wall 500 mm lens camera photography Comprehensive sample Single or double drive core tube Panoramic photography Documented sampling of crater at edge of rille Possible pan on edge of crater Penetrometer
Travel	1:56	0:03	Along rille rim at the Terrace	Continued description of rille and rim material Photography as appropriate
10	1:59	0:10	Along rille rim at the Terrace	500mm lens camera panoramic photography—provides stereo base for station 9; same targets should be photographed Documented sample from crater on rille rim Panoramic photography
Travel	2:09	0:06	Along rille rim to north end of the Terrace	Continued description of rille and rille rim material Photography as appropriate
11	2:15	0:10	At rim of Hadley Rille at NW end of the Terrace	Observe and describe rille and far rille wall; compare with previous observations 500mm lens camera photography Documented samples of rille rim and crater at edge of rille Panoramic photography
Travel	2:34	0:07	From rille rim and traverse across mare toward North Complex	Compare rille rim material with other terrain Observe changes in material from rille rim to mare to North Complex

TABLE 2.—*LRV Exploration Traverse*—Continued

Station/activity	Elapsed time at start (hr:min)	Segment time (hr:min)	Geological features	Observations and activities
			EVA III—Continued	
Supplementary Sample Stop	2:41	0:05	Between rille rim and North Complex	Soil/rock sample Panoramic photography
Travel	2:46	0:12	Toward Chain Crater in the North Complex	Observe changes in material from rille rim to mare to North Complex Observe characteristics of crater chain originating in Chain Crater Observe possible secondary craters
12	2:58	0:23	Southeastern rim of Chain Crater in North Complex at junction with elongate depression	Documented sample of crater ejecta Documented sample of North Complex material Panoramic photography Possible drive core tube Describe wall of crater and its relation to elongate depression Attempt to determine whether crater was caused by impact
Travel	3:21	0:08	Between large craters in North Complex	Observe area between craters in North Complex and compare ejecta with other materials at the site Continue to compare North Complex with other terrain types
13	3:29	0:53	Multiple objective stop at end of North Complex between Chain Crater and 700-m crater	The more interesting features in the North Complex are the following: 160-m crater on western rim of the 700-m crater 700-m crater Eaglecrest Crater Scarps Based on the characteristics and accessibility of each of these features, the following tasks should be completed at the discretion of the crew: Documented sampling Panoramic or stereo panoramic photography Possible drive core tube Exploratory trench Soil sample Targets for 500mm photography Penetrometer
Travel	4:22	0:19	From North Complex into the mare region with possible secondaries from ray	Observe and describe differences in material and surface textures between North Complex and mare Note amount of secondary cratering Photography as appropriate
14	4:41	0:20	180-m crater in mare south of North Complex	Compare blocks and mare material with North Complex Documented sample of mare material Possible fillet/rock sample Possible large and small equidimensional rock samples Possible radial sampling of fresh 5-10m. crater Panoramic photography Exploratory trench in ray material
Travel	5:01	0:15	Across mare between North Complex and LM	Describe differences between this area and other mare areas Note distribution of possible secondaries
LM	5:16	0:44	Smooth mare fill	Store samples and records Ingress LM

TABLE 3.—*Summary Timeline for ALSEP Deployment*

Approximate time at start of activity (minutes)	Commander's activity	LM pilot's activity
0		Both remove ALSEP from LM and stow it on ROVER
10		Both remove ALSEP from LM and stow it on ROVER
20	Drive Rover to ALSEP site	Walk to ALSEP site
30	Heat Flow Experiment Removes equipment from Rover and sets up on moon.	Make electrical connections to ALSEP
40	HFE—Continues to deploy equipment	Deploy Passive Seismic Experiment (PSE)
50	HFE—Assemble drill	Solar Wind Experiment Lunar Surface Magnetometer (LSM)
60	HFE—Drill first hole, place probes in first hole	LSM
70	HFE (drill second hole)	Install sunshield Install ALSEP antenna
80	HFE—Place probes in second hole	ALSEP antenna SIDE/CCIG
90	Drill core sampling	Activate ALSEP Central Station
100	Drill core sampling	LRRR—Photos of ALSEP
110	Drill core sampling	Photos of ALSEP

TABLE 4.—*Principal Investigators for the Apollo 15 Lunar Surface Scientific Experiments*

Experiment	Principal investigator	Institution
Passive Seismic	Dr. Gary V. Latham	Lamont-Doherty Geological Observatory Columbia University Palisades, New York 10964
Lunar Surface Magnetometer	Dr. Palmer Dyal	Space Science Division NASA Ames Research Center Moffett Field, California 94034
Solar Wind Spectrometer	Dr. Conway W. Snyder	Jet Propulsion Laboratory Pasadena, California 91103
Suprathermal Ion Detector	Dr. John W. Freeman	Department of Space Science Rice University Houston, Texas 77001
Heat Flow	Dr. Marcus E. Langseth	Lamont-Doherty Geological Observatory Columbia University Palisades, New York 10964
Cold Cathode Ion Gauge	Dr. Francis S. Johnson	University of Texas at Dallas Dallas, Texas 75230
Lunar Geology Experiment	Dr. Gordon A. Swann	Center of Astrogeology U.S. Geological Survey Flagstaff, Arizona 86001
Laser Ranging Retro-Reflector	Dr. James E. Faller	Wesleyan University, Middletown, Connecticut 06457
Solar Wind Composition	Dr. Johannes Geiss	University of Berne, Berne, Switzerland
Soil Mechanics	Dr. James K. Mitchell	Department of Civil Engineering, University of California, Berkeley, California 94726
Lunar Dust Detector	Mr. James R. Bates	Science Missions Support Division, NASA Manned Spacecraft Center, Houston, Texas 77058

U. S. GOVERNMENT PRINTING OFFICE : 1971 O - 426-187